CPE Comments and Topics

Gap bridging

THE keen spirit of enterprise in the contemporary industrial scene is in many ways due to the fact that entirely new industries have arisen phoenix-like from the ashes of an older industrial background. These have required the services of a new type of professional person who is essentially versed in the fundamentals of two or three of the classical sciences. One example of this is nuclear engineering. The nuclear industry which arose immediately following the second world war required an engineer who was essentially versed in nuclear physics and chemical engineering.

Turning to the biochemical industry, we find that much the same need has also arisen there. This particular industry comprises several of the oldest branches of chemical manufacture like brewing, as well as several of the more recent branches like antibiotics. For many years it was run entirely by biochemists and microbiologists who directed production from the vantage point of their laboratory bench; 'practical' matters like design and construction of fermentation plant or selection of pumps and valves were left entirely in the hands of the technician, who gained his empirical know-how by experience. That this state of affairs is impossible in a progressive 20th-century industry was soon realised, and the need arose for a 'biochemical engineer'—essentially a chemical engineer who understands the mechanism of biochemical processes.

The symposium arranged by the Institution of Chemical Engineers on biochemical engineering last month surveyed the tremendous scope of this subject, at the same time underlining how wide was the gap between microbiologist and biochemical engineer on the one hand, and chemical and mechanical engineer on the other. Discussing fermentation techniques, in an opening paper, Dr. D. J. D. Hockenhull, a microbiologist, pointed to the continuous fermentation process of penicillin developed by M. Johnson in 1953. This antibiotic was first produced by continuous addition of glucose and phenylacetic acid while controlling the *p*H by adding acid or alkali. The process entailed new methods of continually adding solutions that have a tendency to sediment; hence pumps and metering devices capable both of withstanding sterilising temperatures and handling slurries had to be designed. In addition, suitable provision had to be made for continuously and accurately controlling *p*H. This has completely changed the outlook in this industry, according to Dr. Hockenhull. The old procedure of simply arranging the initial conditions, loading up the fermenter, setting off the fermentation and letting it drift on whatever metabolic winds and tides may spontaneously occur, has had to be abandoned.

Rather a different approach to this subject was made by Prof. Calderbank, who described previous work on factors determining the dissolution rate of oxygen in aerated and mechanically agitated liquids. It was shown that small spherical bubbles are formed when aqueous solutions containing hydrophilic solutes are aerated and the mass-transfer coefficient between gas and liquid was given. It became possible, consequently, to determine the rate of oxygen supply from bubble clouds to agitated liquids (taking into account an additional rate-limiting factor of oxygen diffusion from the bulk liquid to the surface of the organism). By comparing such equations to the dissolution of solid particles in mixing vessels, when these particles are completely suspended in agitated liquids, the conclusion was drawn that small bubbles move through liquids in the same way as spheres. Experiments were undertaken to measure the mass transfer from the fluid to the solid interface using a dispersion of ion-exchange particles in a mixing vessel as an analogue of mechanically dispersed organisms in a nutrient fluid. Such experiments showed that the above process is likely to be rate determining in many industrial fermentations.

Basic chemical engineering studies of this nature undoubtedly give a closer understanding of the various mechanisms that occur during a biochemical reaction. Unfortunately, too few chemical engineers are at present occupied on such basic problems. Yet it is to the credit of the brewing, antibiotics and sewage industries that they now appreciate the extent to which chemical engineering can help them. The recent establishment of a Guinness lectureship in biochemical engineering at University College, London, is a good indication of this trend. There seems very little doubt that during the next decade the biochemical engineer will become as important a gap-bridger as the nuclear engineer has already proved to be during the past decade.

Isotopic flow measurement

MR. L. PUTNAM, head of the isotope branch of the U.K.A.E.A. isotope research division, recently published a comprehensive survey concerning applications of isotopic techniques for nuclear engineers. In the U.K., radioisotopes have been available in quantity since the Harwell reactor BEPO began to operate in 1948.

Perhaps one of the most revolutionary applications of radioisotopes is in liquid flow measurement; the advantage of such tracer methods over conventional flowmeters is that measurements are given in absolute units and introduce no obstruction to the flow. C. G. Clayton, in *Atom*, **21** (50), describes three methods suitable for measuring turbulent flow of water in pipes, all of which are capable of an accuracy better than 1% as well as being cheaper to install and applicable

to dirty water. In two of these methods all measurements are made from outside the pipes, so that the only access required is for the injection of a few millilitres of solution. Obstructions in pipes can be located by introducing a γ-emitting tally into the system. For example, a rubber ball containing sodium-24 has been used to locate obstructions in a mile of buried sewage pipe by following it above the ground with a portable γ-ray detector.

A method has also been developed of testing for internal leaks in heat exchangers, by introducing a radioactive solution into the primary circuit, which will appear in the secondary circuit if a leak exists. The actual size of the leak is determined by measuring the activity in the secondary circuit with an external γ-ray detector. In fact, a special leak-detection system based on these lines has been developed for the internal pipe of the effluent pipeline at Winfrith. A device to measure the time interval between arrival of an injected tracer in the central pipe and its arrival *via* a leak into the outer pipe enables the leak to be rapidly located.

Desalination by electrodialysis

ISRAEL'S Negev Institute for Arid Zone Research in Beersheba has been investigating the problem of desalination of underground waters for many years. In a detailed survey issued by the Institute recently, it is pointed out that electrodialysis provides potentially the most suitable and economic process available at present. Special difficulties are encountered when attempting to electrodialyse natural waters found in Israel's desert region, the Negev. Owing to the presence of particular types of salts in these waters precipitation occurs in the membrane deposits and these hard scale deposits interfere with the efficiency of the process as well as increasing power consumption.

When work in this field started some three years ago in Beersheba, emphasis was laid on developing the electrodialysis method for large-scale desalination and to arrive at a process which would provide cheap irrigation water for Negev settlements. A pilot plant was set up, designed to operate continuously at an output of about 30 cu.m./day. of water. In the course of the testing period a new system of scale control was developed which is considered to be an improvement over previous methods, since its application does not involve the use of complicated equipment for chemical treatment and is generally applicable to all types of plant. More recently, a prototype of a compact desalination plant was designed and constructed which is capable of providing small quantities of fresh water continuously and automatically from brackish water. This 'household' unit, which can produce 1,000 l./day of drinking water, is only a little larger than a radio cabinet.

The ultimate plan is to build a full-size operating unit to process about 1,000 tons/day of water. With such a unit the economical feasibility of the electrodialysis system for the irrigation of the Negev region could be evaluated.

Chemical engineering laboratories

WITH the increasing attention currently being paid to chemical engineering education both by the government and by industry, it is inevitable that new chemical engineering laboratories and pilot plants are being opened at many universities and technical colleges. This is a most satisfying state of affairs, but it inevitably brings new problems in its wake: how to design a teaching laboratory (often on a limited budget) and enable the student to become acquainted with the fundamentals of chemical engineering science and technology.

In most cases, of course, the laboratory forms an integral part of the general course work which itself is normally geared to the examination requirements. There are three different kinds of chemical engineering courses at present in this country. Firstly, the university course, leading up to the degree in chemical engineering. Secondly, the technical college course, recognised by the Institution of Chemical Engineers and leading up to graduate or associate membership of the Institution. Thirdly, there is the newer breed of colleges of applied technology which prepare students for the diploma in technology. The standard of this Dip.Tech. is reputed to be on par with a degree, but it is still too early to assess its value in practical terms.

In our special feature on chemical engineering laboratories and pilot plants in this issue, two different types of chemical engineering laboratory are described. Profs. Heertjes, Kramers and Vlugter of the world-famous Delft Technical University discuss the organisation of their laboratories and pilot plants which are used both for training and research. Perhaps the most remarkable feature of the Delft laboratories is the inter-relationship between the study of unit operations and their function in chemical processes. In this way basic principles of heat transfer and fluid flow are related to processes which are actually being carried out on a pilot-plant scale. Mr. S. D. Holdsworth, who recently established a chemical engineering course at Borough Polytechnic, has a far more modest budget at his disposal. He has shown that many pieces of plant may be used for more than one purpose in teaching chemical engineering fundamentals. Moreover, the fact that in most technical colleges there is some course on applied chemistry (rubber, plastics paints) allows the student to study process engineering in practical cases.

New copper process

A NEW copper-producing plant that will turn low-grade ores into high-quality copper without a melting step anywhere along the line, may well herald the end of the age-old method of producing copper by conventional melting processes.

This plant, estimated at $23 million, will be built in the Philippine Islands by Foster Wheeler Corp. and the E. W. Bliss Co. One reason why this plant should have long-reaching effects on future copper-producing projects is because the capital cost of this installation is 40% less than conventional smelting,

refining and casting plants. The process makes it possible to obtain high-grade copper products from any starting material currently used in the copper industry and has the additional advantage that it can handle complex ores such as copper-zinc combinations, more effectively than by conventional methods. Once the plant starts operation it should produce immediate improvements in the economy of the Philippine Islands. With an estimated annual output of 14,000 tons of fabricated copper products this plant will be capable of satisfying all local requirements. In addition the plant will produce 100,000 tons of ammonium sulphate fertiliser as well as 5,000 tons of zinc for use in the galvanising industry.

Superheat reactor

WHAT is probably the world's first superheat reactor, the Vallecitos experimental superheat reactor, will soon be constructed by the U.S. General Electric Co. in California. It is interesting to note that in order to finance this superheat project almost $6 million has been provided by a consortium of seven New York companies known as the Empire State Atomic Development Associates. The reactor was designed to permit many types of fuel to be irradiated for screening or long burn-up with variable conditions of temperature and steam flow, in order to evaluate fuel performance over a range of heat-transfer conditions. Provisions are being made for simple and rapid exchange of fuel samples. Defective fuel elements may also be used for evaluating the potential levels of contamination of turbine and condenser systems in large plants, and of maintenance problems involved in operating similar equipment in a contaminated state.

The superheat reactor will be housed in a conventional dry containment building situated about 50 yd. from the present 50-MWT Vallecitos boiling water reactor installation (where earlier test programmes demonstrated the feasibility of nuclear superheat). This proximity permits the supply of steam generated by the boiling water reactor to the V.E.S.R. for superheating.

The reactor will be light-water moderated and cooled by a combination of moderator boiling and forced convection cooling with saturated steam. The initial plant rating will be 12.5 MW. This rating is expected to be increased as the experimental programme continues. The reactor core will be contained within a pressure vessel approximately 33 ft. in length, operating pressure of the vessel being 1,000 p.s.i.g. with an operating temperature of 545°F. The initial reactor core will consist of 32 fuel assemblies each made up of nine fuel elements. The fuel elements will have hollow centres so that heat can be transferred to the saturated steam from both the inner and outer surfaces of the element. The full core loading of 288 fuel elements will contain about 5,300 lb. of sintered UO_2 in the form of annular pellets. The fuel, enriched 3.6% with U^{235}, will be compacted to approximately 95% of theoretical density.

Steam for cooling the superheater fuel elements can be obtained from either the gas-fired boiler, the boiling water reactor, or a combination of both. The saturated steam will be admitted into the top of the reactor vessel and there will mix with a small amount of saturated steam rising from the boiling moderator. The steam will then flow down the outer annulus of each of the process tube bundles. After passing around the outer surface of the fuel elements in the lower end of the process tube, the steam will make a 180° turn and then pass upward.

Research in glass

THE output of Pilkington Bros. Ltd. comprises every conceivable glass product including flat glass, optical glass, glass fibres, insulators and cathode ray tubes (with the possible exception of chemically resistant glass). Pilkingtons are undoubtedly one of the largest glass manufacturers in the world, and it came as no surprise to find that their new research centre at Lathom, near St. Helens (built at a cost of £2 million with equipment valued at another £2 million) is probably the largest single research laboratory of any kind in this country.

It may well be asked why there is so much need to carry out basic research in glass science and technology on such a lavish scale? The answer was perhaps given by Dr. Lawrence Pilkington, director of research at Pilkington Bros., who stated that his firm could either try to lead the world in research or rely on buying patents and processes from other companies at a price that was always high, and sometimes prohibitive. Pilkingtons therefore chose the former course and decided to invest substantially in the most up-to-date research equipment available. This research centre, which was recently inaugurated, deals with every type of research and development work, ranging from applied mathematics to glass technology. It is still not quite clear to physicists what the 'glassy state' really means. The classical definition of glass as a super-cooled liquid is no longer tenable, since to all intents and purposes glass at atmospheric temperature exhibits no measurable creep (unlike even the most highly viscous liquid). The newer tendency is to treat glass like an amorphous inorganic polymer, exhibiting many of the rheological characteristics of organic polymers.

One of the most noteworthy aspects at Lathom is the amount of research devoted to the design and constitution of refractories for glass furnaces. The glass furnace constitutes a major and costly item of equipment (often costing more than £1 million) in the production cycle, and molten glass at a temperature of 1,500°C. is one of the most corrosive media known. As a result, the lifetime of a refractory is relatively short (from one to three years). The impact of chemical engineering on glass production is hardly noticeable, despite the fact that continuous processes mainly operate in this industry. The difficulties associated with the glass furnace would be a good point at which some chemical engineering principles could be usefully applied to gain a better understanding into the basic principles of glass-making.

Trading eastwards

THE phenomenal success which the British Trade Fair encountered in Moscow last month was not entirely unforeseen. Many of Britain's more far-sighted industries have paid, during the past five years, particular attention to Soviet and East European markets, realising that these markets would tend to expand with increasing attention being paid to consumer industries throughout the Soviet bloc. For political reasons American industry is unable to compete in exporting to this market, therefore the only two Western countries selling to the Soviet bloc have been the U.K. and Western Germany. Even two years ago Western Germany was leading in the export of chemicals, but she has now been overtaken by the U.K.

The most important British chemical company exporting to the Soviet Union is undoubtedly I.C.I., who had the largest stand at the Moscow Fair and sent over a team of 200 staff for this occasion. At the recent I.C.I. annual general meeting the chairman, Mr. Paul Chambers, drew attention to the important changes currently taking place in I.C.I.'s pattern of export trade. Thus the volume of I.C.I. sales to the British Commonwealth appears to be rather static. The same could be said for I.C.I.'s sales to America, whereas I.C.I.'s sales to the Common Market countries and the European Free Trade Area (outer eight) have risen by about 25%. More significantly, sales to Soviet bloc countries have increased by no less than 60%; in fact, I.C.I. sells more to that area than to the U.S. There seems every indication, according to Mr. Chambers, that this satisfactory state of trading with Europe, both East and West, will persist and that these new markets will give that considerable security and resilience in exports that would be absent if too high a concentration of trade were directed on the Commonwealth and the Americas.

Powerful combination

AFTER their recent merger with W. J. Bush & Co., Albright & Wilson are rapidly becoming one of the most formidable groups, particularly in the fine chemicals industry. It will be recalled that A. Boake Roberts & Co. joined the A. & W. group about one year ago and this has already resulted in increasing the group sales by £8 to £42.5 million, as was revealed in their 1960 annual report.

The main core of the A. & W. group is still the original Albright & Wilson (Mfg.) which was founded in 1851 to produce phosphorus. Nowadays, this company has six plants mainly producing phosphorus and its compounds. Another large subsidiary company is Marchon Products, who make industrial and household detergents, shampoos and cosmetics as well as a wide range of surface-active chemicals with detergent and emulsifying properties. Solway Chemicals make substantial quantities of sulphuric acid from calcium sulphate which is used by Marchon in the manufacture of sodium tripolyphosphate. A. Boake Roberts & Co. manufacture a wide range of plasticisers, stabilisers and fine chemicals such as essential oils and flavouring essences. W. J. Bush & Co. also make essential oils, flavouring compounds, fruit juices and food colours as well as bulk organic chemicals, pharmaceuticals and dyestuff intermediates and drugs. Midland Silicones (in which Dow Corning has a part interest) is one of the largest manufacturers of silicones in Europe producing all ranges of silicones from lubricants and release agents to elastomers.

The main products of the A. & W. group are therefore phosphorus compounds and fine chemicals mainly for perfumes, cosmetics and food flavours. It can now be expected that a certain rationalisation in essential oils manufacture will occur. This branch of the chemical industry has traditionally been a batch-scale industry relying to a great extent on empirical know-how. The introduction several years ago by Boake Roberts of the continuous Glidden process for synthesising geraniol from turpentine, was the first indication that essential oils production was moving into the 'continuous process' era. The merger of Boake Roberts and Bush within the same group should do much to standardise the manufacture and quality of essential oils and other fine chemicals.

Instant snow

MOST of us, whether young or old, have a predilection at some stage in our life to reminisce about the weather. Unfair comparisons inevitably occur as a result of such reminiscences: winters are never as cold as they were in our childhood and summers never as hot. Much of this kind of behaviour may be ascribed to psychological sentimentality. Nevertheless, do we not often hear world-wide complaints that there really is a shortage of snow in contemporary winters—even in Switzerland!

Snow deficiency, however, does not unduly perturb us, living as we do in the nuclear age. Surely if we are capable of sending rockets to the moon, a minor problem such as producing 'instant snow' is really only child's play. Consequently, we were not surprised when we were informed that the Larchmont Engineering Co. of the U.S. had recently developed a snow-making machine to cater especially for the numerous ski resorts in the U.S. and Canada for whom lack of week-end snow in the season is ruinous.

Man-made snow requires two basic elements: compressed air and water in a fine, high-pressure mist. In the newly developed snow machine, the water is atomised by a 2-in. split case, high-pressure centrifugal pump and the air is compressed by a 60-h.p., 3,600-r.p.m. electric motor. Movable nozzles are mounted on sleds and water is fed in up to a maximum rate of 10 gal./min. at 90 p.s.i. The air feed is 100 cu.ft./min. at 100 p.s.i. pressure. Water and air are mixed at the base of the sled and shot out in atomised form creating a heavy fog blanket in which the snow crystals are formed. The machine can produce in one hour not less than 2 in. of snow covering an area of 2,000 sq.ft. at a temperature of 30°F. The cost of covering a typical slope with a 6-in. blanket of artificial snow has been estimated at only between £40 to £50.

Chemical Engineering Pilot Plants

By Prof. Dr. Ir. P. M. Heertjes,* Prof. Ir. H. Kramers† and Prof. Dr. Ir. J. C. Vlugter‡

The Institutes of Chemical and Physical Technology at Delft Technical University are amongst the best-equipped chemical engineering laboratories in Europe. Much careful work has gone into the planning of the chemical engineering courses by the authors, who are professors at the Technical University. Their article discusses the function of these chemical engineering laboratories and pilot plants in the training of chemical engineers and shows that very good results are achieved by combining plant units ranging from small-scale to semi-technical production scale, at the same time enabling the student to familiarise himself with actual chemical processes.

THE pilot plants to be described here are not pilot plants in the ordinary sense of the word. They are not normally used as one of the steps in the development of a laboratory process to a full-scale chemical plant. They rather serve as semi-technical aids in study and understanding of the fundamentals of a technical chemical process or a physical operation. They are, therefore, primarily used for the practical education of students in chemical engineering. A small part of this educational programme consists of familiarising the students with rather large equipment by manual handling. The largest part of the practical work, however, has a research character, because in our opinion research work is the best way to make students develop themselves in the field. Therefore, the greatest use made of the semi-technical apparatus is for research work.

In order to give a description of the pilot plants, the background necessary to understand their set-up and purpose, it seems worth while to present first, in some detail, the Delft chemical-technology curriculum with which most of the readers of this journal will not be familiar.

Chemical-technology curriculum

The programme is based on five years of university training. Enrolment can start after successful completion of the final examination of one of the two grammar schools which give access to the technical university. These final examinations are held throughout the country under supervision of the Ministry of Education.

The first two academic years in the faculty of chemical technology are devoted to the study of mathematics, chemistry and physics. An examination called ' Propaedeutisch Examen ', which can be taken in two parts, gives access to further study. The next two years, therefore (the academic third and fourth year), also comprise the study of fundamental subjects (mainly chemistry in its different aspects) and the study of technical subjects. The most important of these are: chemical technology, physical technology (transport and separation processes) and mechanical technology. These two years are concluded with the so-called 'candidaatsexamen'. The level of this examination is roughly equivalent to a B.Sc. degree in the Anglo-Saxon countries; it is, however, not recognised as a final examination. Roughly speaking, the subjects up to the ' candidaatsexamen ' cover 50% theory and 50% laboratory work.

The study in the fifth year, leading to the final examination and degree ('Ingenierusexamen', 'scheikundig ingenieur ' (Ir.), roughly equivalent to a M.Sc. degree) comprises relatively more laboratory work and less theory. A full year is used to carry out research work, only two theoretical subjects having to be studied during that time.

Finally, it is possible to obtain a doctor of technical science degree (Dr.), which generally takes about three years of research work. Laboratory work in chemical technology is carried out by students in their third and fourth year as part of the current programme, by students in their fifth year who have chosen to work with one of the professors in chemical technology or chemical engineering and by those working for a doctor's degree, again by their free choice.

Laboratory training

The laboratory work in the third year for the technical subjects takes eight weeks (five afternoons per week, that is about 160 hr.), equally divided in time between chemical technology and physical technology. It serves as an introduction to this field and is handled in semi-class-like manner. In the fourth year the students may select one of four possible directions into which the course work has been divided and, according to their choice, they may have to carry out technical laboratory work ranging from 8 to 22 weeks. In the most technical of these directions, the students will have to work for 10 weeks on chemical technology and for 12 weeks on physical technology. Laboratory work in the fourth year consists of research work and is carried out on a far more

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independent basis than work in the third year. The research subjects are, of course, adapted to the level of the students. In some cases the students work on their own; in other cases they assist graduate students or those working for their doctorate thesis, but even then they are supposed to undertake a separate small research project.

The subjects to be studied determine in which place they will be carried out—whether in one of the laboratories or in one of the three pilot-plant halls.

It must be appreciated that semi-technical equipment is always placed in one of these halls. Nevertheless, fundamental technical work is also carried out in these halls in small apparatus. In some cases this combination is due to space limitation only; in the majority of cases, however, it has a more fundamental background because, in general, many important phenomena can be found and examined with small-scale apparatus which can be checked on technical apparatus. Such work, therefore, has to precede work on technical equipment and can be profitably carried out side by side with this work.

Equipment of the pilot-plant buildings

The function of the pilot plants, and therefore the layout, is determined by its utilisation, which follows from the above. One of its principal characteristics is that it has to be dynamic in nature. The most static part consists of the semi-technical equipment which is used for manual handling by third-year students, or for production purposes. These are, for example, distillation columns, filter presses, centrifuges, a cement kiln, an extraction battery, a thickener, autoclaves, a plant for catalyst manufacture and evaporators. It will be appreciated that by a combination of some of these units a semi-technical-scale process can be imitated.

This gives an opportunity to study such a process, generally with the object to try and find improvements of certain aspects. These processes are operated by students each working in 8-hr. shifts. An example of such a course is the production of sugar from sugar beets in which a novel method of extraction is studied where SO_2 or chloroform is used in order to lower the extraction temperature and decrease the amount of impurities; this involves new ways of purification of the raw juice with the aid of ion exchangers as well as a study of filtration. Although such plant is static in nature, one of the problems here involved is to use apparatus which is as modern as possible. This requires continuous renewal as well as continuous completion. In many cases, new equipment is ordered from outside manufacturers according to our own designs which are adapted to the needs of the laboratory. In such designs the help of the mechanical department is often required. Two examples of such new equipment are:

(1) An electrically heated distillation column with 10 bubble-cap plates (8 in. diam.), with a possibility of altering the distance between plates from 3 to 12 in. The column can operate under vacuum and up to 140 p.s.i.

(2) A multi-purpose reactor, to be used for the study of different kinds of chemical processes.

Perhaps more important than the conventional equipment just mentioned, which has after all a relatively long life, are the assemblies based on our own concepts and designed for research work in special fields. The construction of such apparatus takes place in the workshops of the laboratory. It should be stressed that the speed with which the construction and the subsequent changes can be realised is some measure of the efficiency of the pilot-plant services. With this special equipment, sometimes expanded from the laboratory process, most of the original research work is carried out. The number and type of apparatus of this kind is continuously changing. Moreover, the size changes from small-scale to semi-technical. A few examples of research work carried out at present using the accompanying pieces of equipment are tabulated below:

Semi-technical

(1) Filtration under high pressure (1,400 p.s.i.).
(2) Catalytic desulphurisation of mineral oils with hydrogen under high pressure (1,000 p.s.i.).
(3) Synthesis of isoprene.
(4) Dehydration of alcohols to olefines.
(5) Dimerisation of propene.
(6) Cracking of paraffin wax.
(7) Distillation in a rotating disc column.
(8) Drying of solid substances.
(9) Condensation of a binary vapour mixture.
(10) Spray drying.

Small-scale

(1) Extraction and absorption in forming, ascending and coalescing drops and bubbles.
(2) Mass and heat transfer in fluidised beds.
(3) Mass and heat transfer between a gas and a liquid on a rotating disc.
(4) Filtration of ferric hydroxide sole.

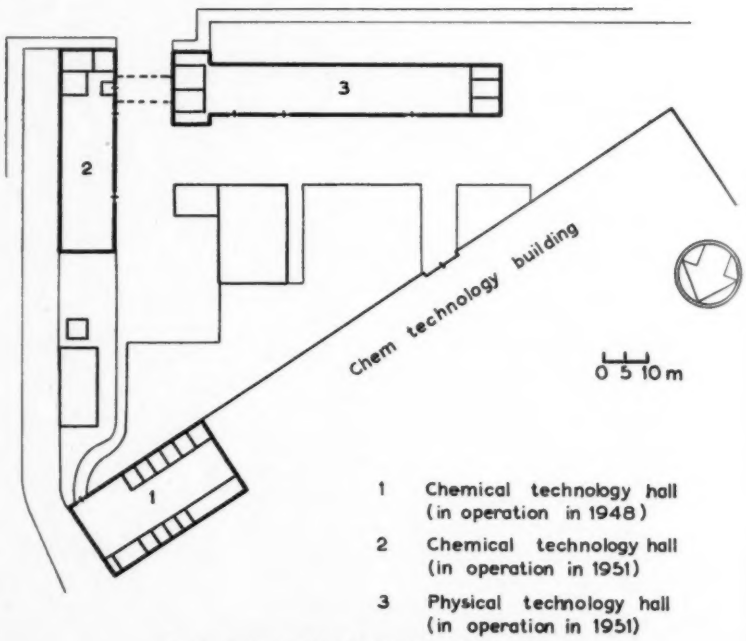
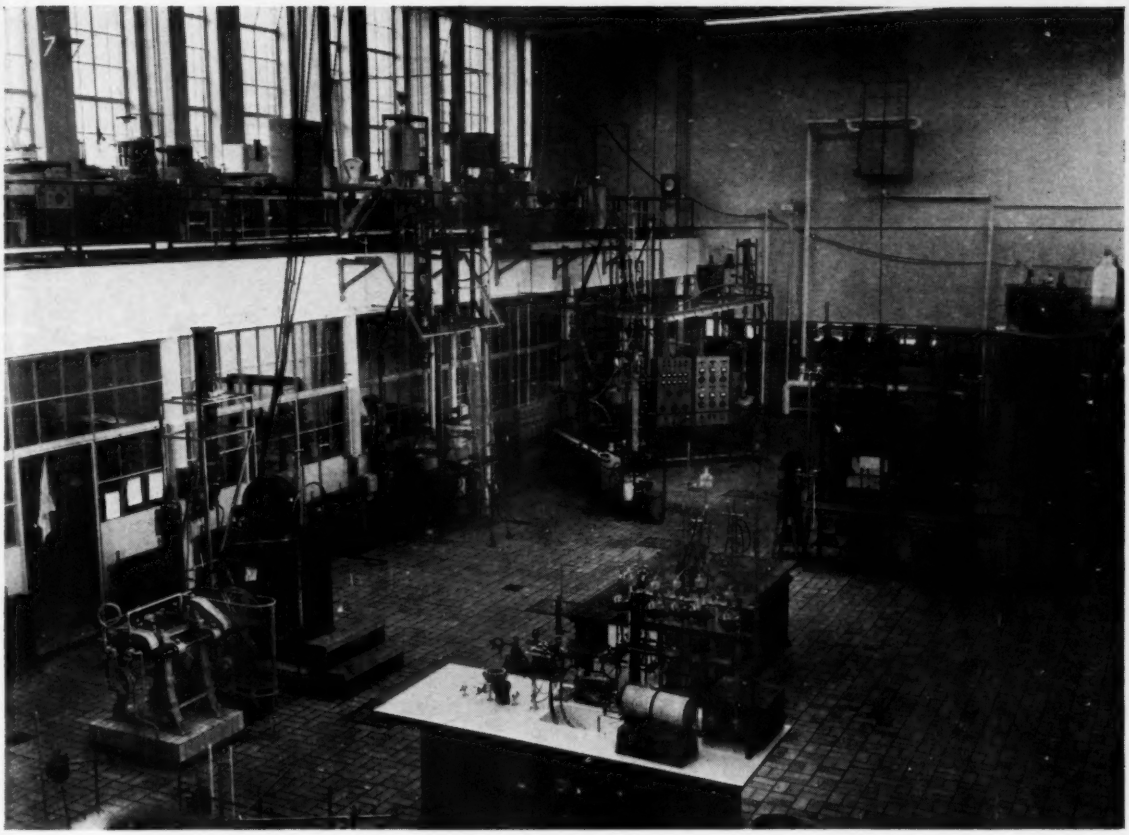

3
2
Chem technology building
0 5 10 m
1
1 Chemical technology hall (in operation in 1948)
2 Chemical technology hall (in operation in 1951)
3 Physical technology hall (in operation in 1951)

Fig. 1. Pilot-plant hall in chemical engineering centre



View of pilot-plant hall No. I

(5) Gas absorption in liquid jets and films.
(6) Residence time distribution in chemical reactors.

Work carried out in the laboratories of the more conventional type has not been included in all this.

Auxiliary services and personnel

Without excellent auxiliary services and trained technical personnel, the pilot plants could not work properly.

Two workshops for rough construction work are available under our own management with 25 technicians. Each workshop is supervised by an experienced constructor of engineer's status. The workshops have a drawing office and a draughtsman at their disposal. It may be remarked here that it is our policy that neither students nor any members of the staff carry out their own construction work. This, in our opinion, saves time and trouble and, in addition, increases the safety considerably and its disadvantages are not significant.

Besides workshop personnel, a few technical officers, again of engineer's status, have to supervise existing equipment in each pilot-plant hall and give recommendations for renewal and replacement. Finally, two porters in each hall are responsible for cleanliness and are used as general help.

Apart from this local help, assistance is also available from a central department fine-mechanical workshop and from the central workshop of the university.

Electronics play an ever-increasing role in the research work that has to be carried out. This has necessitated the introduction of an electronic workshop with three engineers who can design, construct, or advise on buying all the electronic and electrical equipment. Examples of their work are manifold: reflux regulators, counting the number of drops, measuring the time of formation of a drop, automatic temperature control, measurement of electrical capacities, etc.

Measuring instruments can receive rough handling, especially from younger students. Despite strict rules and penalties for misuse, it too frequently happens that an instrument becomes unreliable. It has therefore been necessary to engage an engineer in charge of controlling all the measuring instruments.

Storerooms provide space for measuring equipment, small instruments, materials of construction for those chemicals which have to be used in large quantities and which are not available in the central storeroom. Storekeepers are responsible for the correct manipulation and bookkeeping of all the goods. The great number of different orders, the rapid changes in the apparatus often necessary and the great care with which the constructions have to be carried out due to, for example, safety considerations, demands well-equipped and well-manned workshops. Moreover, from the personal point of view, it is also necessary that the technical staff possess great flexibility of mind as well as good sporting qualities.

Organisation

We have endeavoured to set up an organisation which allows for a maximum of possibilities for research

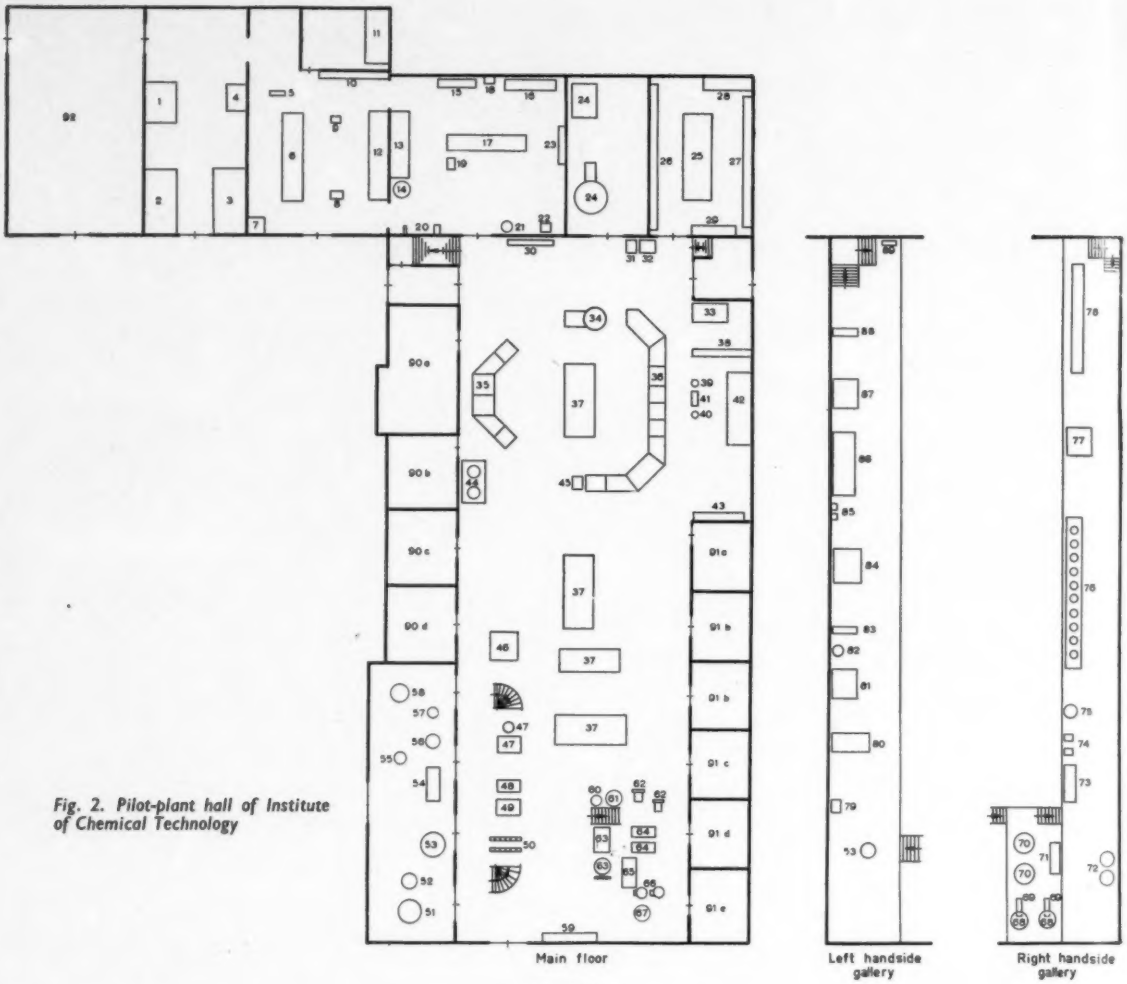


Fig. 2. Pilot-plant hall of Institute of Chemical Technology

Legend:

1-2	Welding tables
3	Spray booth
4	Smith shop
5	Automatic hacksaw
6-7	Worktable
8-9	Metal shears
10	Toolchest
11-12-13	Worktables
14	Drillpress
15-16-17	Lathes
18-19	Toolchests
20	Grinding apparatus
21	Drillpress
22	Nabbler
23	Toolchest
24	Steam generator
25	Laboratory table
26-27	Laboratory apparatus racks (*Dexion*)
28	Acid hoods
29	Laboratory table
30	Steam reduction centre
31-32-33	Electric ovens
34	Centrifuge
35-36	Laboratory apparatus racks (*Dexion*)
37	Laboratory tables
38	Stand-oil apparatus
39-40	Sugarbeet extraction apparatus
41	Sugar diffuser
42	Acid hood
43	Titration table
44	*Quickfit* distillation columns
45	Hydraulic press
46	Steam-heated laboratory mill
47	High-pressure filtration apparatus
48	Sweetland press
49	Plate and frame press
50	Service panels for 51-58 inclusive
51	*Dowtherm* autoclave 301
52	Transformer, 50 kW
53	Distillation column, 200 l.
54	Petroleum distillation column, 100 l.
55	Rotating disc column (glass)
56	Isobutanol distillation column
57	Distillation column
58	Rotating disc column
59	Vacuum pump
60	Carbonating tank
61	Sugar syrup tank
62	Pump
63	Edwards pump
64	Sugar syrup tank
65	Condenser
66	Condensate pots
67	Basket centrifuge
68	Sugar crystallisers
69	Mixer
70	Evaporators
71	Storage tank for lean syrup
72	Calcium carbonate storage
73	Syrup purification apparatus
74	Plate and frame presses
75	Storage tank, raw syrup
76	Sugar diffuser
77	Sugarbeet shredder
78	Rotary cement kiln
79	Voltage stabiliser, 25 kW
80	Vibration-filtration
81	Fluidisation
82	Air reducer
83	Drying apparatus
84	Single-plate bubblecap column
85	Toolchests
86	Work table
87	Fluidisation apparatus
88	Drying apparatus
89	Pressure regulator
90a	Draughting room Technical supervision
90b	Weighing room
90c	Special research
90d	Laboratory attendant
91a	Assistant
91b	Special research
91c	Chief assistant
91d	Assistant
91e	Work room
92	Storage of materials

workers and students. A rather sharp separation has been made between education and research on one side and management on the other.

The responsibility for education and research work lies with the professors. Each has independence and complete freedom to operate in his field as he sees fit and as far as his budget allows. Each is supported by scientific staff who help in the laboratories and whose members in some measure relieve the teaching load and some of the supervision and who themselves carry out research work under the supervision of their own professor.

Responsibility for the management of such an institute lies in the hands of one of the professors. This is not a permanent job, but it changes, perhaps, once every three years.

The managing professor has, for example, to make the estimate of accounts for each year, supervise the budget, purchase apparatus and chemicals, select new personnel, make recommendations for expansion of the institute, etc. It goes without saying that, because he also has a full teaching and research load, he needs a considerable amount of help. Directly under him works a scientific permanent officer called ' Bedrijfsingenieur ', with strong interests in mechanics, whose task it is to prepare all the decisions to be made by the managing professor. It is also encouraged that the ' Bedrijfsingenieur ' participates in research work. Practice has shown that this managing officer is generally far too occupied with his main tasks to do so personally.

The line of organisation from here onwards is not quite the same for the two institutes.

In the larger of the two institutes, directly under the ' Bedrijfsingenieur ' there are two officers to whom part of the work has been delegated. One of these is the engineer responsible for the workshop, who is in charge of the other technical staff; the second is a man in charge of purchases and storerooms, the supervision of the porters, safety measures (fire brigade) and first aid. Administrative help is present to carry out the routine work.

Contacts between the scientific sector and the managing sector are manifold. One example will demonstrate this. An apparatus is required and a sketch of this apparatus is made by the research worker. After consultation with and approval of the assistant concerned and, if need be, discussion with the supervisor, it is handed over to the superintendent of the workshop who will prepare a construction design. After approval of all those concerned, the apparatus will be constructed, tested and handed over to the research worker. During this whole period contact must exist between the scientific and technical personnel.

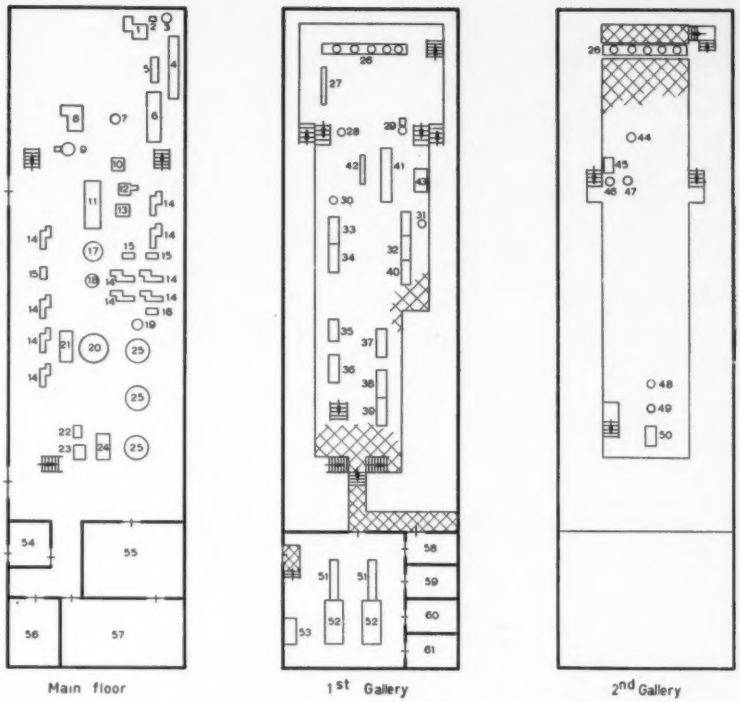


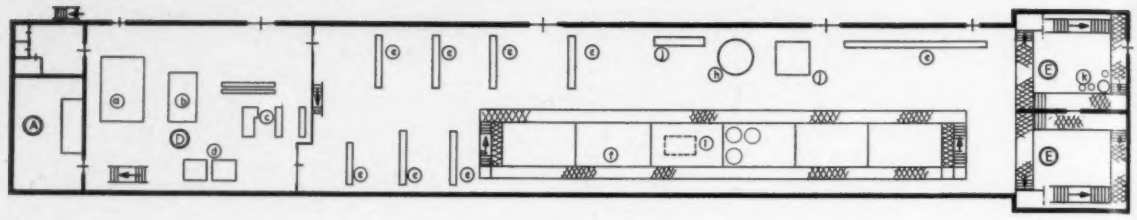
Fig. 3. Pilot-plant hall of Institute of Chemical Technology

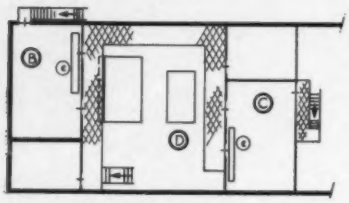
Legend:

1	Hydraulic pump
2	Valve block
3	Air accumulator
4	Air container, 700 p.s.i.
5	Lathe
6	Working table
7	Autoclave, 5,600 p.s.i.
8	Container with pump
9	Water container with pump
10	Electrical-driven compressor (14,000 p.s.i.)
11	Reducing oven for catalysts
12	Compressor for hydrogen (14,000 p.s.i.)
13	Compressor (42,000 p.s.i.)
14	Gas circulation pump
15	Lubricating oil pump
16	Pump
17	Granulating machine
18, 19	Tabloid machines
20	Dorr thickener
21	Filter press
22, 23	Compressor for ethylene
24	Membrane compressor
25	Gasholder
26	Multi-purpose unit
27	Panel for 26
28	Bleacher
29	Mixing tank
30	Cooling tank
31	Column reactor
32	Unit for high-pressure hydrogenation
33	Unit for catalytic reforming
34, 35	Units for catalytic conversion processes
36	Fluidisation apparatus
37	Unit for hydrogenation of fatty oils
38	Dimerisation of propene
39	Copolymerisation of styrene and linolic acid
40	Hydrocracking of paraffin wax
41	Apparatus for hydrogenation of sucrose
42	Panel
43	Worktable
44	Container
45	Steam ejector
46	Cyclone
47	Deodorisation vessel
48	Dryer
49	Ball mill
50	Mixer
51	*Dexion* racks
52	Laboratory tables
53	Acid hoods
54	Cloakroom
55	Store room
56	Lavatory
57	Technical superintendant
58	Assistant
59	Storeroom
60	Weighroom
61	Assistant

Pilot-plant buildings

Fig. 1 shows how the three pilot-plant halls are grouped together into what may be called the chemical engineering centre. Hall No. 1 is a part of the building for chemical technology, which in its turn is the





A Instrument storage
B Laboratory for physical measurements
C Chemical laboratory
D Utilities
E Tower

a Large steam boiler
b Small steam boiler
c Compressor and vacuum pumps
d Cooling water pumps

e Racks for smaller experiments
f Steel structure for support of larger equipment
g Circulation evaporator
h Spray dryer
j Film evaporator
k Distillation column with automatic controls
l Equipment for wet grinding, classication and filtration

Fig. 4. Pilot-plant hall of Institute of Physical Technology

back part of the large laboratory building for chemistry. Halls Nos. 2 and 3 are later additions which were built from a grant from industry.

Layout of the buildings

In Figs. 2 and 3 the layout of the two pilot-plant halls of the Institute of Chemical Technology are shown. In Fig. 4 the same is presented for the pilot-plant hall of the Institute of Physical Technology, showing the main equipment and some of the auxiliaries. As these figures seem self explanatory, only a few additional remarks will be made.

The utilities in the three halls are: gas, water, compressed air, steam and electricity (220 and 380 V). They can be taken from mains which follow the contour of the halls and have equally spaced taps. Water and gas come from outside the building, compressed air is taken from a compressor in hall No. 3 and steam can be obtained either from a compressor from the university's central boiler-house, from oil-fired boilers in hall No. 3 (5 and 0.7 ton/hr. respectively) or from a small, movable, electrically heated boiler.

The halls are heated *via* a hot-water central-heating system or by means of hot air obtained from small, separate units placed at the wall of the halls. These units provide for the possibility of forced ventilation. Each hall is provided with a travelling crane for the transport of heavy equipment. For the smaller equipment, lorries are used.

Each hall has the traditional protection against fire hazards: sand, small and large CO_2 extinguishers, water showers over each outside door, blankets and a pipe and hose system inside and outside the halls. Two trained fire brigades have been formed from the personnel. Some of the personnel have been trained in first aid.

Conclusion

It has been said in the beginning that the pilot-plant halls described do not serve in the industrial sense of the word. They are mainly used to familiarise the students with semi-technical equipment and in this way to increase their insight and to prompt them, if possible, to find new methods. They contain much equipment of a most diversified nature, but this all serves the one main purpose. It must be kept in mind, moreover, that the pilot plants belong to a university subsidised by the government. It is understandable that in the evaluation of a chemical process, in view of the limited sources available, the second semi-technical stage can hardly be surpassed. Further work on the same process must be carried out elsewhere.

Nuclear power conference

About 100 scientists from all over the world recently attended a nuclear power conference at Berkeley, Gloucestershire, organised by the Central Electricity Generating Board. The subject of the meeting was 'Properties of Reactor Materials and the Effects of Radiation Damage'.

The conference followed the official opening of the nuclear power station laboratories at Berkeley, which have been established by the Generating Board to carry out research and development work in connection with Britain's civil nuclear power programme.

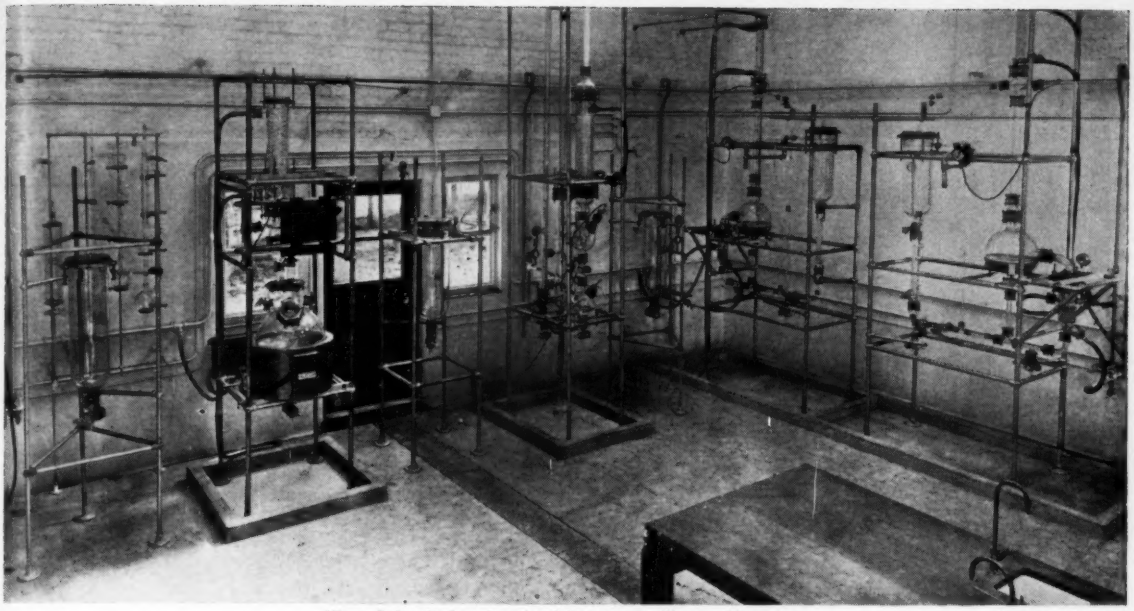
Standards Engineers' Conference

The view was expressed by a speaker talking on 'Standards and Market Research' at this year's Standards Engineers' Conference that some British standards were perhaps unnecessarily severe in the level of performance required of them. He instanced in particular such standards as those for transformers, flameproof enclosures and tower cranes in which, he thought, the safety margin was often fixed at a point unrealistically high. The speaker suggested that the British Standards Institution should set up a market research advisory committee.

Plutonium experimental reactor

LAMPRE 1, a molten plutonium experimental reactor, achieved criticality recently at the Los Alamos scientific laboratory. This reactor is part of the laboratory's programme to develop and test fast breeder reactor concepts, to help evaluate the idea of using metallic plutonium as a fuel in the liquid, rather than in the solid state.

The fuel region, or core, of the reactor is about 6 in. high and 6 in. diam. Small capsules of tantalum metal are used to contain the fuel in the core. Heat is removed from the fissioning fuel by a circulating stream of molten sodium.



View of chemical engineering laboratory at Glasgow University [Courtesy Q.V.F. Ltd.

Laboratories for Training Chemical Engineers

By S. D. Holdsworth,* M.Sc.

With the ever-increasing number of new chemical engineering departments which are currently being opened at universities and technical colleges it becomes increasingly important to equip their laboratories with the optimum equipment for teaching and research. This article discusses the organisation of a chemical engineering laboratory with particular reference to a technical college (which usually has various other applied chemistry departments). Equipment for studying heat, mass and momentum transfer is surveyed and examples are given how such equipment may be used to study chemical process engineering.

THE design problem in every chemical engineering course has a logical and indispensable place in the training of a professional engineer. It does, in fact, form an admirable conclusion, although it is often spoilt by its close proximity with final examinations. It reveals to the student who is unfamiliar with design procedures the difficulties which may be encountered in tackling a problem scientifically from first principles. The situation, unfortunately to some extent, appears worse than it actually is, because of lack of experimental or pilot-plant data.

The place of laboratory work by comparison, in a chemical engineering course, is less well defined and is rather neglected for a variety of reasons. It is often assumed in the case of full-time students that adequate experience is gained during vacation courses and part-time students already have an accumulated industrial background. It is also neglected because of lack of facilities and maintenance staff. Few teachers would disagree that laboratory work carried out under good supervision was anything other than advantageous. The development of the faculty of critical observation, the interpretation of results and exercise in report writing are probably the three most important advantages of carrying out laboratory work. This account is an attempt to summarise some of the different types of laboratory work which may be of help to students in gaining an insight into chemical engineering operations. It is specifically confined to the technical college where the aim of the student is A.M.I.Chem.E. or alternatively a diploma in technology. It is not, however, concerned with laboratory layout or services, as these are usually problems of local environment.

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Laboratory demonstration units

Units of this type can be of immense value to the student in helping him to understand more clearly the mechanisms of various operations as well as to develop the faculty of critical observation. It is not suggested that these should be used exclusively for qualitative study, but with suitable instrumentation and facilities they could also be used more quantitatively. A typical example of visual observation incorporated in a laboratory pilot plant is the availability of glass windows in a plate distillation column. Unfortunately, the plates are usually small and the field of view somewhat restricted; as a result, very little insight into the operation of a bubble-cap plate can be gained. The windows, in general, only serve to warn the operator of flooding conditions. An interesting system by which to study the operation of contacting devices of the plate type involves the use of 18-in.-diam. plates (one or more), standard glass pipe and flanges and an air-water system. The apparatus can easily be dismantled and alternative types of plate substituted, thus introducing a considerable degree of flexibility.

Table 1 summarises briefly, and by no means exhaustively, some other types of system which can be included under this general heading of demonstration units. The visual sections can be made of glass or perspex in non-thermal systems. Considering a further example of useful experimental work, the problem of scale-up of mixing devices is illustrative. A series of glass vessels from 3 in. to 2 ft. in diameter, respectively, together with suitably scaled stirrers, can be conveniently used for illustrating the effect of Reynolds and Froude groups on the scale-up. Fluids of different density and viscosity can also be used to advantage in illustrating these principles.

To stimulate further interest an 8- or 16-mm. cine-camera can be used to obtain a permanent record and to illustrate reports.

Table 1

Class	*Experimental unit*	*Observations*
(1) Mass transfer	(*a*) packed columns (water/air system)	Flooding characteristics. Distribution of phases
	(*b*) Plate contacting devices (*e.g.* bubble caps)	Hydraulic gradient. Vapour flow characteristics
(2) Heat transfer	(*a*) Submerged wire technique using electrical resistance heating circuit	Boiling mechanisms
	(*b*) Water-cooled (copper) pipe/steam	Film and dropwise condensations
(3) Mass-heat transfer	(*a*) Climbing film evaporator	Flow régimes and film development
	(*b*) Spray-drying unit	Size distribution
(4) Momentum transfer (fluid flow, etc.)	(*a*) Fluid flow through pipes of various diameters and around objects	Characterisation of flow régimes using a dye injection technique; study of scale-up principles
	(*b*) Fluidisation (solid/gas)	Effect of particle size on the distribution and régime
	(*c*) Mixers	Flow patterns using dye injection or foil and study of scale-up principles

Unit operations study

This section is concerned with the quantitative rather than qualitative behaviour of equipment, although, as previously mentioned, both aspects may in some cases be conveniently combined within the same unit. The ultimate problems in this section are the size of equipment and materials of construction. Both are interrelated with regard to initial cost and ultimately to maintenance and processing materials cost. It is generally thought to be advantageous to have at least one manually operated pilot plant to enable a group of students to organise the operation. A double- or triple-effect evaporator capable of removing 300 to 400 lb./hr. of water and arranged on three floors is suitable for studying heat and material balances. An alternative or additional unit is the two-plate distillation column. The major problem encountered when operating a large unit intermittently is corrosion, since it is rarely possible to afford high-corrosion-resistant materials.

The majority of units will in general be relatively small; suitable examples are given in the Institution of Chemical Engineers' publication 'Notes on Laboratories for the Teaching of Chemical Engineering' and also in the references contained therein. Tables 2 and 3 outline some experiments which can be included in general laboratory programmes. Two general points of importance may be mentioned in passing, concerning instrumentation and analytical facilities. The lack of instrumentation on many commercially available pieces of equipment, and non-availability of the latter, reduce considerably the amount of useful information which can be obtained. Analytical facilities should include a variety of types of equipment for the determination of particle size, *i.e.* sieves, elutriators, microscopes and sedimentation balances, for the characterisation of porous media, *i.e.* apparent density, porosity, permeability and surface area equipment, and for obtaining equilibrium data and transfer coefficients, *e.g.* equilibrium stills, wetted wall columns and disc columns.

Heat-transfer study

Conduction, convection and radiation are most easily studied in connection with the heat lost from lagged and unlagged steam pipes from a small steam boiler. The temperature profile for various thicknesses of lagging can be determined and also the optimum thickness. The exercise is instructive in as much as it gives an insight into the economics of chemical plant services. An interesting experimental verification of the fact that counter-current heat exchange is more efficient than co-current can be obtained, together with other information from an arrangement consisting of two concentric tube stainless-steel heat exchangers connected in series. The first has water flowing from a constant-head tank through the tube with condensing steam on the outside, and the second has the hot water from the first flowing through the inside of the second and cooled either co-currently or counter-currently by water or oil flowing in the jacket. Similarly, the availability of such items as a small tube and shell heat exchanger or a plate type of exchanger can also prove interesting, especially if adequate instrumentation is included for temperature, pressure and flow rate

measurement. As previously mentioned, heat-transfer experiments can be carried out in jacketed stirred reactors containing coils to determine the heat-transfer coefficients and efficiency, apart from using the results as a measure of the efficiency of mixing.

To a large extent unsteady-state processes seem to have been neglected in the teaching of chemical engineering; this is reflected in the limited number of experiments currently in use to illustrate the principles. These experiments are suitable for more advanced students because of the increased complexity of the analysis and involve relatively simple time-temperature profiles or even evaluation of the time required to produce a liquid continuously at a given temperature. The results can be compared with the relevant theory if an analytical treatment is possible.

In conclusion to this section, the subject of analogues might conveniently be mentioned here. The availability of electrical and hydraulic analogues to simulate either steady-state or transient heat transfer is most useful in demonstrating to students a method of solving complex problems. This is particularly relevant to the study of counter-current and co-current flow.

Fluid flow units

Generally, most laboratories are well equipped to study fluid flow and there is also considerable use for this type of equipment in studying instrumentation and control. Table 4 summarises the various types of equipment that can be classified under this heading.

Project investigation

It is in connection with chemical process investigations that technical colleges have a considerable advantage over universities because a variety of applied chemistry subjects are usually taught there; for example, plastics, dyestuffs, paint or food technology. These branches of chemistry generally require considerable quantities of raw materials for teaching purposes. These can be supplied to some extent from well-equipped pilot-plant laboratories and, as a result, the student chemical engineer is enabled to gain wide range of laboratory experience by working on the production. A pilot-plant laboratory for carrying out processing can also be invaluable to research departments who may wish to process a material under extreme conditions or to scale-up a production. Quite often, a small firm with limited chemical equipment may wish to avail themselves of the facilities to produce small batches of new materials. A further justification for having these facilities available for chemical engineering students is in their use for obtaining data for the design problem. Some examples of advanced projects which could be carried out in a well-equipped laboratory will now be mentioned.

The production of phenol or urea-formaldehyde resins can be carried out within a 2- or 3-gal. jacketed reactor with facilities for stirring, refluxing and batch distillation. The initial reaction between phenol and formalin in the presence of oxalic acid catalyst is carried out under refluxing conditions and the water of condensation removed by vacuum distillation. Similarly the acetylation of cellulose to give cellulose acetate can be carried out effectively in a suitable vessel with refluxing device. More ambitious projects involve the use of continuous flow reactors of the jacketed tubular type for gaseous chlorination of ethylene or propylene to produce vinyl or allyl chloride. The main problem is one of temperature control, in particular the maintenance of a uniform temperature. The evolution of hydrogen chloride and its absorption to produce acid is also interesting. Following the production of monomer, the polymerisation or copolymerisation can

Table 2

Unit operation	*Equipment*	*Experimental work*
(1) Filtration	Filter press, 12 in. × 12 in. plates	Constant - pressure filtration. Characteristics of filtration of compressible and non-compressible materials. Effect of filter aids
(2) Sedimentation	Tubes of varying diameter	Sedimentation rates using materials of varying mean particle size
(3) Centrifuging	Perforated basket centrifuge (12 in. diam.)	Filtration rates
(4) Mixing	(*a*) Emulsification equipment	Particle size distribution and stability for varying conditions
	(*b*) Agitated reaction vessel with heating coils (5 gal. capacity)	Effect of stirring rate on heat transfer
(5) Fluidisation	Three-inch-diam. column sintered glass distributor	Study of pressure drop with particle size variation

Table 3

Unit operation	*Equipment*	*Experimental work*
(*a*) Distillation	Ten plate column, 12 in. diam, continuous	Heat balance. Efficiency of plate column at various reflux ratios and varying thermal conditions of feed. Response time for a change in feed condition
(*b*) Absorption	Ten-foot column, 4 in. diam., packed: NH_3/air/water SO_2/air/water CO_2/air/water or caustic	Determination of H.T.U.s and mass - transfer coefficients. Study of effects of various liquid and vapour/gas flow rates. Flooding characteristics
(*c*) Liquid-liquid extraction	(*a*) Five-gallon mixing vessel, $\frac{1}{10}$-h.p. stirrer, variable speed (*b*) One - inch - diam. rotating disc column	Efficiency of devices; mass-transfer coefficients
(*d*) Drying	(*a*) Drying oven, humidity controlled, steam heated (*b*) Vacuum oven	Rate of drying and comparison of drying time with theoretical. Effect of particle size on drying rate
(*e*) Humidification	Spray chamber with reheater	Determination of H.T.U.s
(*f*) Evaporation	Double-effect evaporation	Heat and mass balance; study of B.P.R.

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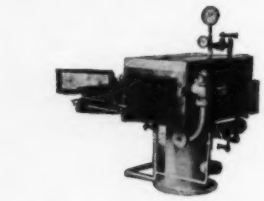

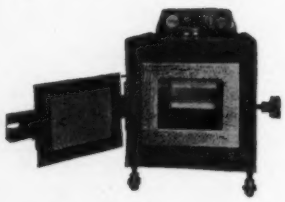

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be studied in a 1-gal. autoclave heated either directly or by induction. The production of silicone resins can be carried out on a small scale. For the initial alkylation of copper-silicon/silver-silicon alloy with an alkyl chloride, a jacketed autoclave can be used with suitable temperature control. The resulting mixture of methylchlorosilanes can then be separated to some extent by distillation depending upon the efficiency of the column. The individual compounds when isolated can then be hydrolysed to give cyclic and linear polymers.

Turning briefly to the manufacture of dyestuffs, coupling reactions are relatively easy to accomplish if the necessary degree of control of cooling can be obtained. The subsequent filtration using plate and frame filter presses and tray dryers can also be performed. Spray or drum drying make alternative interesting studies. A more difficult preparation is that of indanthrene dyes involving essentially three stages. The condensation of chlorobenzene with phthalic anhydride in the presence of anhydrous aluminium trichloride to give 2-chloroanthraquinone is carried out initially. A high-pressure autoclave can then be used to carrying out the animation, usually 1,000 p.s.i. and 200°C. being quite adequate. The final condensation of the amino-anthraquinane with an alkali or other material can be carried out in the stirrer reactor used for the first reaction.

The most common difficulty to be encountered in the operation of reactors under pressure is the sealing of stirrer glands. It can be eliminated by the use of a vibro mixer which has no rotating parts. An added advantage, to mention only one other, is that the degree of mixing can easily be controlled by variation of the frequency of vibration, whereas the speed control of a large stirrer is more difficult to control.

The above-mentioned type of project can only be undertaken where there are adequate facilities and materials. Glass equipment is suitable for reactors not involving pressure, the maximum capacity being of the order of 4 or 5 gal.

Specialised topics

With regard to the more specialised branches of chemical engineering, *viz.* biochemical, geochemical and nuclear chemical engineering, only brief mention will be made here. Although basically the same unit operations are employed, other factors are involved in these which are often outside the range of normal experience.

Table 4

Operation	*Experimental study*	*Related to*
(1) Fluid flow through pipes and fittings	Critical velocity and pressure drop	Reynolds' demonstration unit
(2) Flow characteristics of valves and stop cocks	Pressure drop	Instrumentation and control
(3) Flow through packings	Pressure drop and breakthrough point	Absorption
(4) Flow through porous media (consolidated and porous)	Validity of Darcy's law. Study of molecular flow. Surface area determination	Analytical work
(5) Pumping	Characteristics of pumps	
(6) Flow measurement	Discharge coefficients: V-notch, weir, venturi, pitot tube, etc.	Instrumentation

Biochemical engineering, for example, requires sterilisation, dehydration, lyophilisation and isolation techniques. The field of study embraces the food and pharmaceutical industries, and includes yeasts, fermentation, enzymes and antibiotics, to mention only a few. A typical example for practical work is freeze-drying and accelerated freeze-drying of foodstuffs. The main ancillary laboratory must be equipped for microbiology. The spray drying of milk in an all-glass apparatus has also been used as a student experiment and demonstration.

Geochemical engineering is mainly concerned with crushing of minerals, flotation separation, leaching and roasting techniques. The availability of a particle size analysis laboratory in conjunction with small-scale equipment makes most operations comparatively easy to accomplish.

When considering the nuclear aspects of chemical engineering there are several hazards such as criticality and prevention of the spread of contamination which require careful supervision. The main topics involved are fission product separation, criticality studies and disposal. Practical work which is relatively easy to carry out involves liquid-liquid extraction techniques or ion exchange. Apart from the problems of laboratory design, considerable expense is involved in monitoring equipment.

With regard to measurement of process variables (pressure, temperature, liquid level, fluid flow, etc.), the main experiments involve the determination of sensitivity and accuracy of instruments. A laboratory for this purpose is ideal, but often, if suitable tappings and valves are available, it is possible to calibrate an instrument *in situ*.

Of greater importance in student teaching is the necessity of having suitably constructed equipment for the control of process variables. For this purpose, equipment already available may be adapted by using suitable controllers and measuring instruments. Consider, for example, a jacketed reactor controlled by means of a pressure controller operating from the jacket to the control valve. The heat-transfer coefficient is controlled at a constant valve. If a temperature controller is applied from the reactor contents to the steam control valve on the jacket, isothermal operation can be achieved.

A second example involves the use of a cascade of three reactors, one or more of which can be used at any time. The effect of various combinations of proportional, derivative and integral actions on the reaction time can be studied using a liquid-level controller of the air-pressure type.

Conclusion

In conclusion to this assessment of pilot plants suitable for teaching purposes, it is hoped that attention has been drawn to the requirements of technical college laboratories. It is clear that, if these colleges are going to play an important part in the education and training of professional engineers in the future, considerably increased facilities will be required. In addition, it is also vital for these establishments to provide a firm basis in chemical engineering for all those who are studying branches of applied chemistry. At the moment such a basis is almost universally neglected, and it may be argued that a diploma in technology studies would be better justified in bridging this gap rather than providing an alternative way in which to study chemical engineering, which is, after all, already provided for by part-time study and the full-time university degree.

Pilot Plant for Ceramic Nuclear Fuel Processes

By G. E. Christie,* Ph.D., A.R.T.C., and F. S. Martin,* Ph.D., A.R.C.S., F.R.I.C.

The philosophy behind pilot-plant thinking inevitably tends towards the consideration of techniques capable of high production rates. In pilot plants for developing production processes for UO_2 ceramic fuel it is important, as this article points out, that the capacity of the pilot plant should be nearly full scale; its role being primarily that of assessing processing problems that occur in transition from laboratory scale to the full production unit.

THE approaching start-up of the Atomic Energy Authority's advanced gas-cooled reactor prototype (A.G.R.) at Windscale marks the beginning of the transition from the use of metallic to the use of non-metallic nuclear fuel. Whereas metallic uranium fuels have for some time been produced on the large scale, uranium dioxide production has not yet proceeded to any significant scale. For instance, the amount of uranium consumed in meeting the 1968 target of 5,000 MW(E)[1] will be approximately 2,000 tonnes U p.a. assuming an average burn-up of 3,000 MWD/tonne U; plant to cope with this is available. Beyond 1966-68 there is likely to be a change to non-metallic fuels and one authority[2] has estimated that about 20,000 to 30,000 MW(E) of nuclear generating capacity might be installed by 1975. If this excess capacity arises from the use of non-metallic fuel whose burn-up may reach 10,000 MWD/tonne U, the annual fuel consumption will be 2,000 to 3,000 tonnes U p.a. This throughput may seem small by many chemical industry standards, but the cost of the product is great. Figures for the cost of enriched oxide fuel are not available, but Lorne Gray[3] has reported that the initial fuel costs for natural uranium dioxide canned in zirconium for the CANDU reactor will be $30/lb. weight, or $4,605,000 total for the charge.

With these figures in mind, it is clearly necessary that much attention be devoted to the development of economical and technically sound methods of fuel production. Production routes and fuel element designs are not produced overnight but are evolved over long periods of development with a testing programme under typical reactor conditions.

Pilot-plant philosophy

The use of pilot plant in developing processes for uranium dioxide ceramic fuel has been of great value in modifying laboratory routes for full-scale production. In some instances, *e.g.* the use of automatic presses for compacting the fuel, the size of pilot equipment is identical with that of full-scale production plant; in these cases so many factors control the quality of the product that direct investigation is by far preferable to theoretical scaling-up studies. In other cases, *e.g.* the development of sintering furnaces, much useful information is first obtained from the study of an intermediate-scale design.

For a given laboratory-scale production method, the philosophy of pilot-plant thinking inevitably tends to the consideration of techniques capable of high production rates. The capacity of the actual pilot unit should be on a scale as near as possible to that of actual production conditions and its role should primarily be one of assessing processing problems which occur during the transition from the laboratory bench to the production unit. The result of such experience frequently leads to plant modifications, but it can also lead to a more complex production route. Various facets of these topics are discussed in the following sections using examples taken from our own experience in the fabrication of UO_2 at the Reactor Fuel Element Laboratory, Springfields.

Assessment of scale-up problems

Problems which can arise during the scale-up of any process can be broadly classified into those concerned with (*a*) technological aspects and (*b*) design aspects of the process.

In the latter case, processing in the nuclear field is rather special in that it is essential that the operators be prevented from ingesting radioactive particles. This can either involve the use of protective breathing equipment or the confinement of all dusty operations to an 'active' area such as a glove box or a partitioned area with its own air extract. Two problems arise in the use of 'active' areas. Firstly, it is essential that the operation be carried out easily and efficiently.

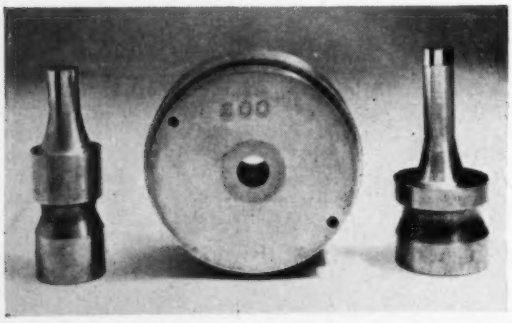

Fig. 1. Tungsten-carbide punch and die set used for compacting uranium dioxide

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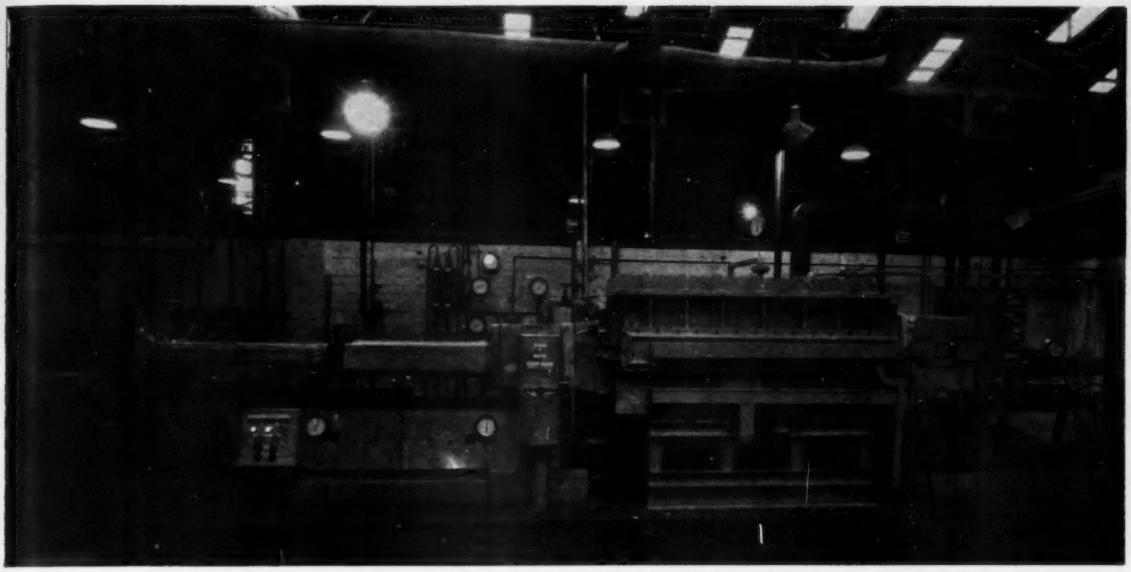


Fig. 2. Furnace for continuous operation in argon at 1,450 C.

In this respect pilot-scale experience can provide very valuable information regarding the location of gloves, manipulators, etc. Secondly, pilot-plant experience may lead to the re-location of pieces of equipment for reasons of accessibility, *e.g.* during maintenance. Our experience has shown that all moving parts such as gear drives, etc., should be protected from dust contamination, either by effective sealing or by locating them outside the 'active' area.

From the technological viewpoint, conditions can still change during scale-up in a process, although the nominal operating conditions such as temperature, motor speeds, etc., remain unaltered. For instance, certain conditions such as the degree of agitation or mixing in, for example, a batch precipitation, are extremely difficult to reproduce in a stepped-up version of the bench model.

An excellent example of this type of problem can be found in the manufacture of raw uranium dioxide for fuel element production. An outline of one possible preparation route is:

$$\underset{\text{(uranyl nitrate solution)}}{UN} \xrightarrow{NH_4OH} \underset{\text{(ammonium diuranate)}}{ADU\downarrow}$$

$$\xrightarrow[>300^\circ C.]{air} UO_3 \xrightarrow[>600^\circ C.]{hydrogen} UO_2$$

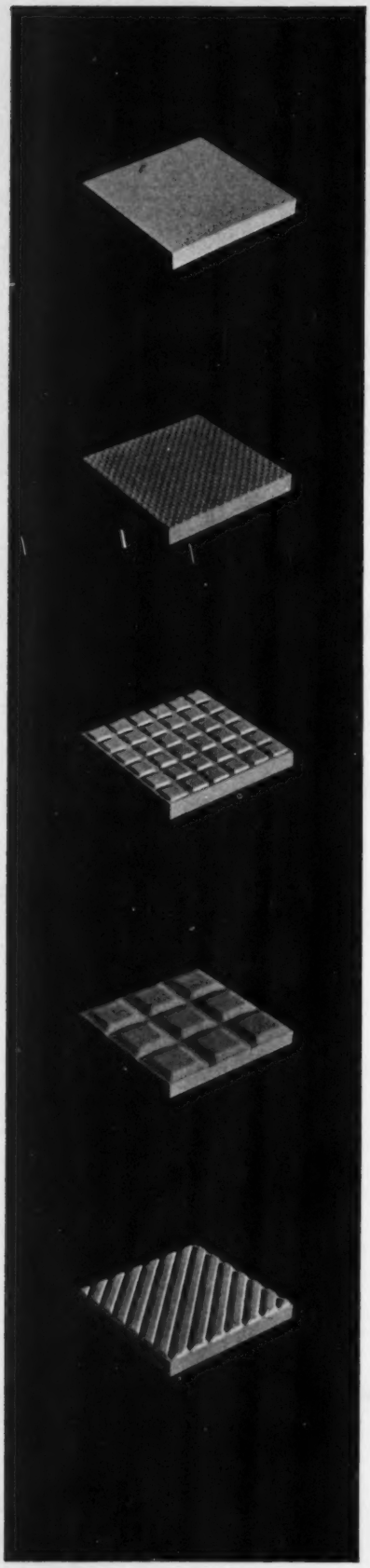
The particle characteristics of the UO_2, which are of great importance in sintering, *viz.* specific surface area, particle shape, bulk density, etc., are dependent on those of the intermediates UO_3 and ADU. In turn these are closely controlled by the precipitation conditions which are dependent upon the stirring rate, paddle design, rate of ammonia addition, etc. The process is further complicated, however, by the fact that the $UO_3 \rightarrow UO_2$ reaction is strongly exothermic, such that the properties of the UO_2 can show wide variations which are dependent upon the rate of heat transfer to and from the powder. On a pilot scale, therefore, new conditions have to be determined which will yield a product of the desired quality and characteristics and, with such a process, it is most desirable that the pilot scale be as close to the actual production scale as possible.

In the production of UO_2, highly enriched in the isotope U^{235}, the further complication arises of using *Eversafe* vessels. These are designed such that their contents, irrespective of the mass present, never become critical; the neutron loss from them is such that a nuclear chain reaction is impossible. They usually take the form of narrow cylindrical vessels and, in the case of the aqueous processing of 93% U^{235} material, are limited to approximately 5 in. diam. By virtue of the geometry of the system, pilot-scale tests are necessary to determine conditions peculiar to this type of equipment and take the form of production-scale trials using uranium of natural enrichment (0.7% U^{235}).

A further example demonstrating the great value of pilot-scale development in exposing scale-up problems was experienced in carrying out a series of large-scale trials aimed at the removal of an organic binder from unsintered UO_2 compacts. (The role of this binder has been explained.[4]) By heating of the compacts in air to around 250°C., the organic binder is removed and the UO_2 becomes oxidised to U_3O_7. The latter reaction is sufficiently exothermic to allow temperatures to rise locally beyond 260°C., at which stage oxidation proceeds to U_3O_8 with the accompanying disintegration of the compacts. Operation at temperatures around 240°C. is associated with large concentrations of residual carbon in the compacts. It has thus been necessary to construct a large debonding unit capable of operating to an accuracy of ± 2°C.

Process and equipment evaluation

Pilot-plant experience can be invaluable in making a general assessment of a process from the point of view of production efficiencies and consistency of product thereby enabling an early and accurate costing of the product to be made. It is also most useful in estimating the expected throughputs during each step of the process such that the final flowsheeting for the production line becomes more accurate and plant layout can be finalised at an early stage with less risk of later interruptions brought about by the installation of additional or alternative plant.



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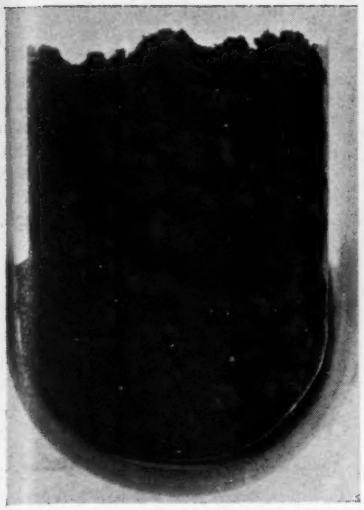

Fig. 3a. Raw uranium-dioxide powder

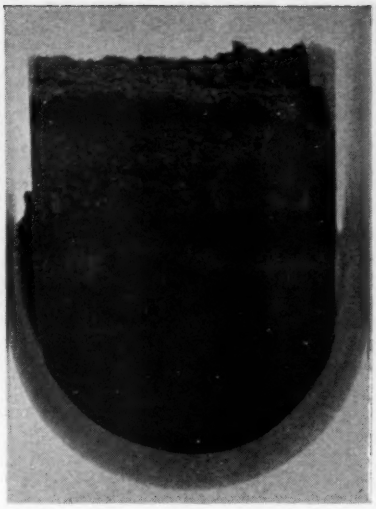

Fig. 3b. Milled uranium-dioxide powder

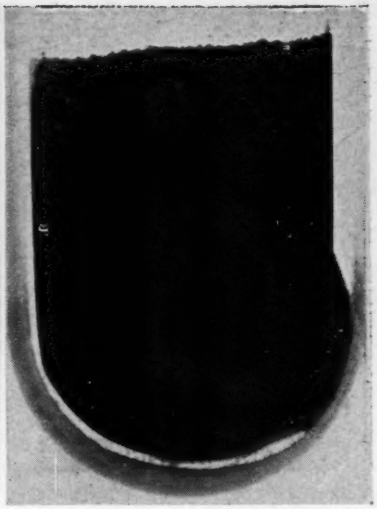

Fig. 3c. Granulated uranium-dioxide powder

Similarly, an estimate of the maintenance schedules required by each item of plant may be made so that pilot-scale experience may either be utilised in actual production or in further design studies. Typical examples of these which have been experienced in the pilot plant for UO_2 fabrication at R.F.E.L. Springfields are described in this article.

From an operational point of view, the expected equipment wear is of great importance. For instance, our experience with tungsten carbide punch and die sets (Fig. 1) has shown that the expected life of a die is about double that of the punch.

Wear on the die usually takes the form of barrelling in the region of compaction and this can be eliminated by lapping with diamond dust. This has only limited success as it invariably alters the punch clearance for that nominal size. To counteract wear our punches are manufactured to a longer length than that specified by the press manufacturers so that the punch head may be replaced on numerous occasions before it is discarded.

More important, however, is wear on equipment which can lead to contamination of the product. For example, rubber contamination may occur as a result of overheating of the rubber mill lining during dry milling of UO_2 powder. Once this problem was detected, the mills had to be relined, but subsequent overheating was avoided by milling batches at suitable intervals, by adjusting the charge weight and by observing the mill temperature before and after each batch operation. A second example of UO_2 contamination arose when wear of the mesh in the granulator was disclosed by the presence of stainless-steel inclusions in the sintered UO_2 pellet. This was eliminated by carefully fitting the blades of the rotor in relation to the mesh.

The importance of pilot-plant experience in aiding further design studies can be seen from the following example. For the large-scale sintering of non-stoichiometric UO_2 pellets, a continuous pusher-type furnace was designed and commissioned to operate in pure argon at 1,450°C. This unit (shown in Fig. 2) consisted of four preheating zones and a main firing zone, heating being provided by *Crusilite* bars placed above the charge. Charging and discharging were carried out through gas locks and movement of the charge was effected by a ram.

A slow steady push on the ram was preferred to intermittent rapid movement of the charge as the latter practice was associated with skewing of the moving refractories and blockages of the unit. For this reason a rack and pinion drive proved to be superior to a pneumatic one. The push load was carried by refractory batts which supported the compacts contained in alumina trays. Although this increased the thermal burden on the furnace, the inclusion of batts was favoured on account of their inherently stronger design; they withstand loading at the operating temperature and are cheaper and more readily available than the robust design of tray which would be required if the latter carried the forward load as well as supporting the UO_2 charge. The successful performance of the unit largely hinged upon the integrity of the batts and this appeared to be controlled by the amount and the rate of thermal cycling experienced during service. There also appeared to be a dependence of batt life upon operating temperture, rate of push, UO_2 throughput and furnace length, and it was estimated that, for a moving refractory bed, the optimum furnace length was 25 ft. With longer furnaces smooth operation could not be ensured because of blockages, etc., while shorter units were associated with low throughputs.

Experience has led to the belief that molybdenum trays and batts would be superior to refractory pieces in a unit designed to operate in hydrogen at 1,600° to 1,750°C. for the production of stoichiometric UO_2.

Influence of pilot-plant thinking on a production route

UO_2 in the form of reactor fuel elements should be of a bulk density greater than 95% theoretical (*i.e.* >10.45 g./c.c.). Because of its high melting point, however, it is more convenient to fabricate it using powder techniques such as hot pressing, cold pressing and sintering, hydrostatic pressing and sintering, etc., rather than by melting and casting.

Each of these techniques can be carried out with comparative ease on a laboratory scale, but only one can be readily adapted to automation and production-scale techniques. Cold compaction and sintering was more attractive than hot pressing. Also, because of added technical reasons such as the problem of sintering large numbers of rods uniformly and free from distortion, cold pressing on a tabletting press was preferred to the

hydrostatic method of compaction prior to sintering.

This is a good example of the shape of a process being determined from pilot-scale thinking, but it will be seen that it also results in increasing the number of operations involved. On the laboratory scale, fabrication consists of compacting in a hand press a weighed quantity of oxide followed by sintering. With the adoption of automatic pressing, however, the first requirement is the provision of a free-flowing powder feed. Standard automatic presses rely on volumetric filling of the die and, unless a granular feed is used, large variations in pellet weight and sintered dimensions result.

Two methods of powder granulation may be used: (*a*) pre-compaction of the oxide followed by breaking up and classification of the required size fraction; and (*b*) subjection to a sequence of milling operations. Fig. 3*a*, *b*, *c* shows the effect on the physical characteristics of milling and the granulation of raw UO_2. The product from both routes flowed well and could be automatically compacted to pellets free from lamination. The physical strength of these compacts was low, however, and they would have suffered severe damage during the handling expected in a production line. Instead of producing a harder and stronger compact, the use of higher pressing pressures gave rise to laminated pellets. It was apparent that, for the large-scale production of a satisfactory green compact, a binding agent had to be incorporated with the press feed.

Binder addition

The incorporation of a binder in the process also had the effect of introducing additional stages, all of which required development on a pilot-plant scale. These included binder addition to the powder, granulation of the mixed material and drying of the granules so produced, classification, and finally the removing of the binder prior to sintering.

The most effective method of adding a binder is in the form of a mobile solution. When using solvents, factors other than the strengthening and adhesive properties of the binder can exert a strong influence on the choice of binder for pilot- and production-scale operation. These include precautions which may be required against fire and toxic hazards which may be associated with the use of large volumes of organic solvents. For example, ketonic solvents or carbon tetrachloride would be required for

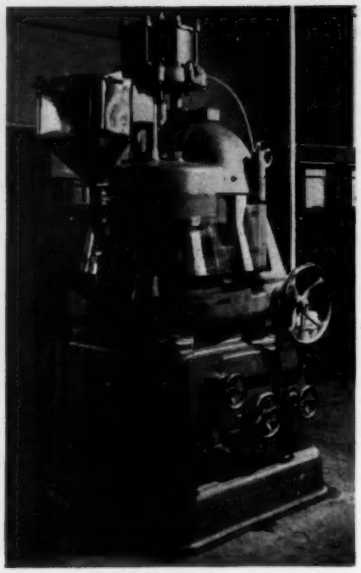

Fig. 4. Mechanical rotary press for mass production of uranium-dioxide pellets

the addition of binders such as perspex type and paraffin wax respectively. In this respect, therefore, pilot-plant reasoning would favour water emulsions or water-soluble binders such as wax emulsions, carbowax polymers or starch. In addition to the handling problems associated with the binder addition, consideration must also be given to the hazards arising during effluent disposal after the binder removal and sintering stages. Both problems could involve the design and use of special flameproof equipment, special air ventilation and suitable plant for the efficient trapping of effluent.

Pilot-plant experience is essential in determining the most suitable automatic pressing conditions. These involved deciding the type of press most appropriate to the process, *viz.* hydraulic or mechanical, rotary or stationary table, and the optimisation of a satisfactory die design, pressing speed and the required size distribution in the feed. The factors which influence the choice of press are mainly capacity, mechanical rotary presses being capable of up to thousands per minute (Fig. 4), while that of hydraulic stationary table presses can be of the order of 5 strokes/min. With regard to die design, the most satisfactory results were obtained from tapered tungsten carbide inserts and hardened steel punches, while the maximum permissible speed was governed by the flow properties, hopper design and feeding arrangements. With a stationary table press, high speeds gave rise to (*a*) less uniformity in pellet weight, on account of variations in die fill. This could be improved by altering the particle size distribution in the feed, but this could increase the load of reject material arising after more rigorous classifying; and (*b*) problems associated with pellet handling and breakage, especially when stacking was practised prior to the following stage.

Product testing

The product from the pilot plant is frequently suitable for the statistical evaluation of qualities such as specific gravity, dimensions of the fuel pellets, freedom from faults such as cracks, chips, etc., and chemical composition. In addition to these, however, a test is required under operating conditions, *i.e.* an irradiation experiment is carried out. In order to achieve an effective irradiation in as short a period as possible it is customary to use test fuels which have been especially enriched in the U^{235} isotope to increase the rating and the rate of burn-up. To comply with the safety requirements of handling enriched uranium for the avoidance of the accumulation of 'critical' masses, the experimental equipment producing these irradiation specimens must of necessity be smaller in scale than the pilot plant hitherto discussed. Hence, since the irradiation test specimen must be identical in nature with the larger-scale product, a pilot plant must be designed on a scaling-down basis as opposed to the usual scaling-up.

All the factors which influence the quality of the product (precipitation conditions in particular) must be re-investigated and the operation parameters suitably adjusted so as to give the required product on a smaller scale. Laboratory apparatus is frequently useful in this type of work; it is also possible, for instance, to use non-automatic presses in place of the high-speed automatic ones.

In normal UO_2 pilot-plant work, it is not unusual to process many tonnes of oxide before satisfaction with the route is achieved. In the production of irradiation specimens, however, a scale of a few kilogrammes is rarely exceeded.

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Chemical Engineering Fundamentals—5

By K. L. Butcher,* B.Sc., M.I.Chem.E., F.R.I.C.

In his fifth article in this series, which examines some chemical engineering fundamentals, the author discusses unsteady-state heat transfer and methods of solving heat-transfer equations. This is related to fluid flow through pipes where conduction and convection heat transfer must be taken into account. The differences between streamline and turbulent flow régimes are stressed.

IT is not intended to discuss cases of unsteady-state heat transfer at length, but the initial aspects of its expression will be given for flow in one direction in a prism of cross-section A normal to the direction of heat flow, and having insulated sides. When the ends of a prism (which was, say, originally of uniform temperature T_0) are suddenly exposed to temperatures T_1 at the hot end and T_2 at the cold end, an unsteady state of heat transfer exists initially, in which at a given position along the heat flow axis (x) the temperature and also the temperature gradient changes with time. Furthermore, during most of this period at any given instant, the temperature and the temperature gradient changes with position. Both of these points are taken into consideration as follows.

A thin slice of conductor (cross-section area A), normal to the heat flow, is taken at a distance x from the hot end along the direction of heat flow. Its thickness is dx. The properties of the conductor are as follows: thermal conductivity k, density ρ and specific heat c.

Suppose the temperature gradient at x is denoted $(dT/dx)_{\delta x}$ and at $x + \delta x$ the temperature gradient is $(dT/dx)_{x+\delta x}$. Considering flow along x as positive, we have that heat is entering the slice at the position x at the rate $q_x = -k.A.(dT/dx)_x$, while at $x + dx$ it is flowing away at $q_{x+\delta x} = -k.A.(dT/dx)_{x+\delta x}$.

Keeping to the convention that the properties at a larger value of x are taken first and the property at the smaller value is subtracted, so that the denominator δx is positive in the differential ratios,

$$(q)_{x+\delta x} - (q)_x = -k.A.\left[\left(\frac{dT}{dx}\right)_{x+\delta x} - \left(\frac{dT}{dx}\right)_x\right]$$

Since dT/dx is varying with x, its rate of variation with x is d^2T/dx^2 and thus, over a finite distance x, the increment in the temperature gradient is (rate of change with distance $\times$ distance), *viz.*

$$\left(\frac{d^2T}{dx^2}\right)\delta x = \left(\frac{dT}{dx}\right)_{x+\delta x} - \left(\frac{dT}{dx}\right)_x$$

Now $(q)_{x+\delta x} - (q)_x$ is the change in q corresponding to the increment δx. Call this dq. Then

$$dq = -k.A.\left(\frac{d^2T}{dx^2}\right)_\tau \delta x \text{ at time } \tau$$

Interpreting this, the flow along the direction of x diminishes (because of minus sign) as x increases. Because dT/dx is inherently negative and is steeper near $x = 0$, then at $x = x$, d^2T/dx^2 is positive. Since the positive flow along x has changed by $-k.A.(d^2T/dx^2).\delta x$ of heat per unit time, an amount of heat per unit time $= k.A.(d^2T/dx^2)\delta x$ is accumulating in the slice. Let the range of change of mean temperature T of this slice be $(dT/d\tau)_x$, where a positive value will be a rise of temperature with time, then another expression for the rate of accumulation of heat is

$$A.\delta x.\rho.c\left(\frac{dT}{d\tau}\right)_x$$

So

$$A.\delta x.\rho.c\left(\frac{dT}{d\tau}\right)_x = k.A.\left(\frac{d^2T}{dx^2}\right)_\tau \delta x$$

or, more simply

$$\left(\frac{dT}{d\tau}\right)_x = \frac{k}{\rho c}\left(\frac{d^2T}{dx^2}\right)_\tau$$

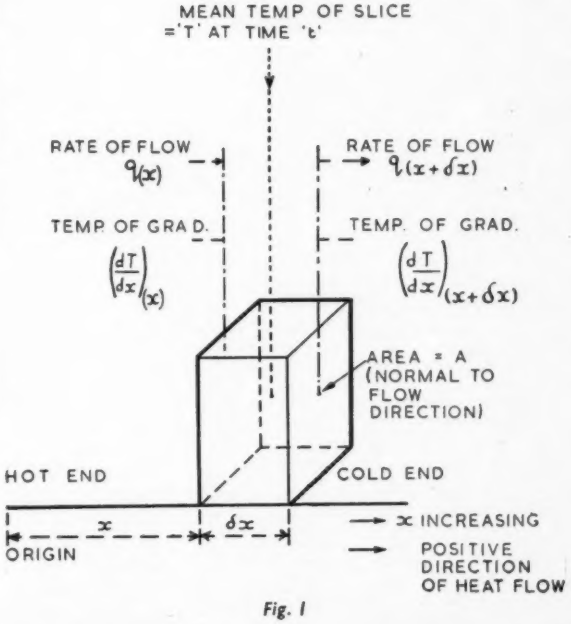

Fig. 1

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Similar considerations apply to three-dimensional flow, so that

$$\left(\frac{dT}{d\tau}\right)_{x,\,y,\,z} = \frac{k}{\rho c}\left(\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2}\right)_{\tau}$$

One of the more difficult problems in heat-transfer calculations is that of integrating the differential equations which may include terms to allow for the convection of heat by moving material and for the internal generation of heat by chemical action, etc.

Solution of heat-transfer equations

The full understanding of the methods of solving the equations requires the acquaintance of the reader with the methods of operational mathematics[1] and with the nature of functions of a complex variable.[2] A powerful tool in dealing with these equations, but of less general application than the operational method, is the application of the Laplace transformation to each term of the differential equation. The effects of this transformation are very similar and often identical with those of the transformation as an operational method. The works of Carslaw and Jaeger[3] and of Churchill[4] expound the application of the Laplace and other transformations. For those who are unconcerned with the proofs of the properties of these operations, but require a clear working account of them directed at heat-transfer problems, Jacob's[5] exposition is recommended. These methods require a definite specification of the initial state of affairs in the system (*i.e.* temperature *versus* position at time = zero).

The above approach leads to analytical solutions of which two examples will be given later. Such solutions are obtainable in simple cases involving regular shapes of uniform material.

Other methods of solution are employed in complicated systems; of these the numerical methods are probably the most powerful and, with the increasing availability of electronic digital computers, most attractive. Numerical methods are, of course, applied in other branches of mathematics such as the solution of algebraic equations of the fourth higher order and to the interpretation of data, so that the works dealing with the subject[6, 7] may seem slow in getting to the problem we are considering. (Whittaker and Robinson give the theory of the method of J. C. Adams and recommend a publication[8] concerning the numerical integration of both ordinary and partial differential equations.) Under this heading comes the relaxation method.[9, 10]

Tantamount to the relaxation methods are graphical methods (frowned on by Jeffreys, p. 290), commonly attributed to Binder (1911) and F. Schmidt (1924), who based it on the calculus of finite differences, and which are described.[11]

Finally, there are analogue methods of solution in which apparatus is set up to enable one to study the flow rate of a fluid or of electricity under the influence of a pressure gradient or a potential gradient, suitable resistance and capacity effects, etc., being included in the circuits so that the differential equations for the flow of water or of electricity would be of the same form as that for the heat problem under investigation.

In the apparatus, if steady-state conditions are established then profiles of head or potential are ultimately established. If transient conditions are of interest, these profiles are examined at frequent intervals of time.[12]

There now follow some more detailed considerations of the matter reviewed above.

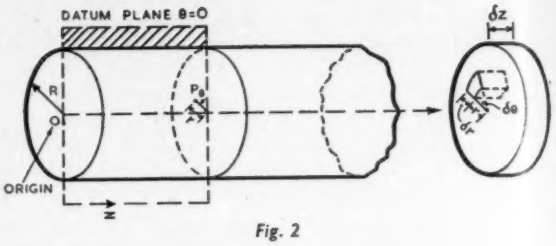

Fig. 2

Modifying the differential equation

Choice of geometric co-ordinates influences the form of the equation. In a cylindrical system it is convenient to describe the co-ordinates of a point by (i) the distance Z from the origin of the projection of the point P, normally on to the longitudinal axis of the cylinder; (ii) the distance r from the Z axis along the normal from the point; and (iii) the angular displacement θ (counter clockwise) of this normal (radius) from a datum, fixed plane containing the longitudinal axis.

Elements of area are of three kinds:

(i) Normal to z direction: $\delta A_z = r\delta\theta\,.\,\delta r$.
(ii) Normal to r direction: $\delta A_r = r\delta\theta\,.\,\delta z$.
(iii) Normal to the tangent for a given θ: $\delta A_\partial = \delta z\,.\,\delta r$ (see Fig. 2).

An element of volume is $dV = r\delta\theta\delta r\delta z$. For a static solid the heat balance on a small element of volume gives:

$$\frac{\partial}{\partial\tau}(\rho.c.dV.T_{abs}) = \frac{\partial}{\partial z}\left(k.dA_z\ \frac{\partial T}{\partial z}\right)_{r,\,\theta}\delta z + \frac{\partial}{\partial r}\left(k.dA_r\ \frac{\partial T}{\partial r}\right)_{z,\,\theta}\delta r + \frac{\partial}{\partial\theta}\left(k.dA_\theta\ \frac{\partial T}{r\,d\theta}\right)_{r,\,r}\delta\theta$$

Rate of accumulation = net inflow minus outflow rates.

Assuming ρ (density), c (specific heat) and k (conductivity) constant, this simplifies to:

$$\left(\frac{\partial T}{\partial\tau}\right)_{z,\,r,\,\theta} = \frac{k}{\rho c}\left[\frac{\partial^2T}{\partial z^2} + \left(\frac{\partial^2T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2T}{\partial\theta^2}\right]_{\tau}$$

If material is flowing through the element of volume dV along z entering at T and leaving at $T - \delta T$, moving with velocity w, then in the fixed element of space there would be an additional accumulation of heat at the rate:

$$(wr\delta\theta\delta r)\rho.c\left(-\frac{dT}{dz}\right)\delta z \quad \text{since} \quad (\delta T_2) = \left(\frac{dT}{dz}\right)\delta z$$

Then

$$\left(\frac{\partial T}{\partial\tau}\right)_{z,\,r,\,\theta} = \frac{k}{\rho c}\left[\frac{\partial^2T}{\partial z^2} + \left(\frac{\partial^2T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2T}{\partial\theta^2}\right]_{\tau} - w\left(\frac{\partial T}{\partial z}\right)$$

Finally, yet another term would appear added to the r.h.s. if spontaneous heat liberation took place due to chemical reaction. Simplification may often be effected by comparing the relative magnitudes of the terms involved.

A steady state of affairs would mean $(\partial T/\partial\tau) = 0$. If, in the cylinder, the moving fluid was a reaction mixture of which the purpose of the surface of the cylinder (pipe) was to cool the fluid, thus maintaining a fairly steady temperature along z, then $\partial^2T/\partial z^2$ might be very small compared with $\partial^2T/\partial r^2$ and $(1/r)\,.\,(\partial T/\partial r)$, and might be

disregarded. Similarly, for a perfectly symmetrical distribution about the centre of the tube, in a plane normal z one would expect at a given radius $\partial^2T/\partial\theta^2$ to be zero.

Thus, for steady state

$$0 = \frac{k}{\rho c}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) - w \cdot \frac{\partial T}{\partial z} + q_{chem}$$

might express the state of affairs in a chemical reactor tube, q_{chem} being the heat of reaction per unit volume per unit time at the temperature T and the concentration pertaining to positions (r, z). At $r = R$, the outer radius of the fluid, the rate of radial flow would be related to the heat-transfer coefficient (a point to be discussed later) and the prevailing temperature. The effective value of 'k' for a fluid in motion depends on the nature of the motion.

A number of cases for solid systems are examined.[13] Having simplified the differential equation, the problem of solving it must be attacked.

Solution of differential equations

Apart from the works mentioned in the review, there are a number of text books[14, 15] in the existing literature designed to assist the inexperienced in grasping the principles of attacking differential equations.

A 'solution' to a differential equation is a relationship between integral quantities such as temperature, time and position, the connection being through a formula involving the physical properties of the materials in the system. Formally the solution might be written $T = f(\tau, r, z)$ which on differentiation in a suitable manner must give the differential equation derived originally for the process under consideration. Many of the equations to be solved are of the second order (*i.e.* involve the second as the highest derivative) and of first degree (*i.e.* the derived functions of highest order appear only as of the first power in the rational and integral arrangement of the differential coefficients).

Familiarity with methods of dealing with the simpler ordinary differential equations (only one independent variable) will be assumed, namely that the solutions of the following are as given:

$$\frac{dT}{d\tau} = A(T - T_0), \text{ gives } \log(T - T_0) = A\tau + C$$

$$\frac{d^2x}{d\tau^2} = -A^2x, \text{ gives } x = Me^{-iA\tau} + Ne^{iA\tau}$$

$$\frac{d^2x}{d\tau^2} = A^2x, \text{ gives } x = Ce^{-A\tau} + De^{A\tau}$$

where A, B, C, D, M and N are constants.

To solve

$$\left(\frac{\partial T}{\partial \tau}\right)_x = \alpha^2\left(\frac{\partial^2 T}{\partial x^2}\right)_\tau$$

where $\alpha^2 = k/\rho c$, first the boundary conditions for the problem to which the equation applies need to be specified. The final form of the solution is governed largely by these boundary conditions, *i.e.* the values of temperature T at the beginning ($\tau = 0$) and ($\tau = \tau$) of the process in time, and at specified distance x along the system. The equation applies to a rod of small uniform cross-section, perfectly insulated along its length (x direction):

(i) Heated at one end (T_1) and cooled at the other (T_0) and initially at T_1 all over.

(ii) With ends kept at a constant temperature T_0 but having an initial temperature along its length given by $T_x = f(x) + T_0$.

One method of attack is to suppose that the final integrated form of the equation is $T = X(x) \cdot F(\tau)$, meaning that the temperature at a given time τ and position x depends on the function of x only, $X(x)$ multiplied by a function of τ only, $F(\tau)$. Thus, since $(\partial/\partial\tau) \cdot X(x)$ and $(\partial/\partial x) \cdot F(\tau)$ can be taken as zero because τ and x are independent, the original differential equation can be built up, for

$$\frac{\partial T}{\partial \tau} = X(x)\ F'(\tau) = \alpha^2\frac{\partial^2 T}{\partial x^2} = \alpha^2 X''(x) \cdot F(\tau)$$

$$\text{Thus} \qquad \frac{1}{\alpha^2} \cdot \frac{F'(\tau)}{F(\tau)} = \frac{X''(x)}{X(x)}$$

Since there is no correspondence between τ and x, each of these ratios must equal a constant, say $-\beta^2$. We then have:

$$\text{from} \qquad \frac{1}{\alpha^2} \cdot \frac{F'(\tau)}{F(\tau)} = -\beta^2$$

$$\text{that} \qquad \frac{d}{d\tau}[F(\tau)]/[F(\tau)] = -\alpha^2\beta^2 \quad \text{or} \quad F(\tau) = e^{-\alpha^2\beta^2\tau}$$

$$\text{Likewise} \qquad \frac{d^2}{dx^2}[X(x)]/[X(x)] = -\beta^2 \text{ or } X(x) = \cos\beta x \text{ or } X(x) = \sin\beta x$$

Thus the alternative solutions are:

$$T = e^{-\alpha^2\beta^2\tau}\cos\beta x \quad \text{or} \quad T = e^{-\alpha^2\beta^2\tau}\sin\beta x$$

The form which fits the boundary conditions must be chosen. The solution for (i) can also be found by operational methods to be:

$$\frac{T - T_0}{T_e - T_0} = \frac{x}{l} + \sum_{n=1}^{\infty}\left[\frac{2}{n\pi}\left(\sin\frac{n\pi x}{l}\right) \cdot e^{-\alpha^2(n\pi/l)^2\tau}\right]$$

(Jeffreys and Jeffreys, p. 564)

Plainly, after a long time, a steady-state case of simple conduction with $dT/dx = (T_e - T_0)/l$ must be established. This accounts for the first term on r.h.s. The transient period in establishing the constant temperature gradient is given by the second term (series), of which a few members may suffice for computation.

Problem (ii) can be solved provided temperature be suitably defined as $(T - T_0)$ instead of T. By making $\beta^2 = (n\pi/l)$, n = any integer,

$$(T - T_0) = e^{-\alpha^2(n\pi/l)^2\tau} \cdot \sin\frac{n\pi}{l}x$$

satisfies the condition that after an infinite amount of time ($\tau = \infty$) the rod should lie uniformly at $T = T_0$ and that, when $x = 0$ and also $x = 1$ at zero time, the temperature should also be T_0. Because n may be given any value and because it can be shown that for linear differential equations the sum of all possible solutions is a solution, then:

$$T - T_0 = \sum_{n=1}^{\infty}\left[a_n e^{-\alpha^2(n\pi/l)^2\tau} \cdot \sin\frac{n\pi}{l}x\right]$$

Since for $\tau = 0$ this gives

$$T - T_0 = \sum_{n=1}^{\infty} a_n \sin\frac{n\pi}{l}x$$

we see that $T - T_0 = f(x)$ should correspond to this. It will do so (Fourier series) if

$$a_n = \frac{2}{l}\int_o^l f(x)\sin\frac{n\pi x}{l} \cdot dx$$

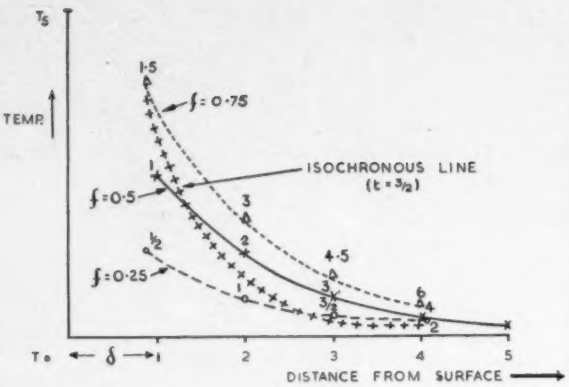

Fig. 3

Thus

$$T - T_0 = \sum_{n=1}^{\infty}\left[\frac{2}{l}\int_0^l f(x) \cdot \sin\left(\frac{n\pi}{l} \cdot x\right)dx\right] \cdot e^{-\alpha^2(n\pi/l)^2\tau} \cdot \sin\frac{n\pi}{l}x$$

(see ref. 16)

Solution by graphical methods

The temperature at position $m \times \Delta x$ units from the origin and at time $n \times \Delta\tau$ units from the beginning of the process may be indicated by $T_{m,\,n}$.

Changes in temperature with time but at constant position can be indicated by $\Delta_\tau T_{m,\,n} \equiv T_{(m+1)n} - T_{m,\,n}$. Similarly, at constant time but varying position: $\Delta_x T_{m,\,n} = T_{m(n+1)} - T_{m,\,n}$; $\Delta_x[\Delta_x T_{m,\,n}] = \Delta_x^2 T_{m,\,n}$. The approximate form of the equation:

$$\frac{\partial T}{\partial \tau} = \alpha^2\frac{\partial^2 T}{\partial x^2}$$

becomes

$$\frac{\Delta_\tau T_{m,\,n}}{\Delta\tau} = \alpha^2\left(\frac{T_{m,\,n+1} - 2T_{m,\,n} + T_{m,\,n-1}}{(\Delta x)^2}\right)$$

Fig. 3 represents the body of a solid subdivided along the direction of heat flow into 'units' of length Δx (arbitrary but equal fractions of the total length L)—(horizontal direction). As ordinate is plotted the temperature at that position, with a subscript to denote the time at which the temperature was measured (in terms of the multiple of a basic arbitrary but convenient time interval).

In the diagram the point P (obtained by the intersection of the straight line $T_{m(n+1)} \cdot T_{m(n-1)}$ with $x = n\Delta x$) is a temperature $T_{(m+1)'\cdot n}$ which from the geometry can be seen to be such that

$$T_{(m+1)'\cdot n} - T_{m,\,n} = T_{m,\,(n-1)} + \frac{(T_{m,\,n+1} - T_{m,\,n-1})}{2} - T_{m,\,n}$$

$$= \tfrac{1}{2}(T_{m,\,n+1} - 2T_{m,\,n} + T_{m,\,n-1})$$

Compare this with:

$$T_{(m+1)n} - T_{m,\,n} = \frac{\alpha^2\Delta\tau}{(\Delta x)^2}[T_{m,\,n+1} - 2T_{mn} + T_{m,\,n-1}]$$

and it will be seen that, provided one selects the magnitude of the time intervals $\Delta\tau$ to equal $(\alpha/\Delta x)^{-2}$, the method of getting P (draw chord) is a convenient one for estimating $T_{(m+1)n}$, *i.e.* $T_{(m+1)'\cdot n} \simeq T_{(m+1)n}$. Obviously, if the temperature curve for time 'm' is rectilinear, this 'curve' is invariable by this technique. Interpreting this statement gives the conclusion that a steady state has been reached. Continued repetition of the construction for $m + 2$, $m + 3$, etc., of course, achieves this end. What procedure to adopt at the surface of the solid, where initially an infinite temperature gradient may exist, is an interesting question which may be viewed as follows.

The limit of the distance Δx that can sensibly be chosen is that of the minimum separation of planes of atoms in a solid, which is of the order of 2×10^{-8} cm. A body initially uniform at T_0, suddenly having its surface temperature raised to T_s and kept at that value, experiences a temperature gradient of $(T_s - T_0)/\delta$, using δ as the separation of planes of atoms. To find the time it would take for the locality adjacent to the surface to achieve a temperature change $f(T_s - T_0)$, where f is a fraction, in view of the absence of a temperature gradient within the body, we use

$$\frac{\Delta_\tau T_{0,\,0}}{\Delta\tau} = \frac{\alpha^2}{\delta^2}[T_s - T_0]$$

Putting $\Delta_\tau T_{0,\,0} = f[T_s - T_0]$ we have

$$\Delta\tau = \left(\frac{\delta}{\alpha}\right)^2\frac{f(T_s - T_0)}{T_s - T_0} = f\left(\frac{\delta}{\alpha}\right)^2$$

Making f, say, 0.05, makes it plausible to say that in the next time interval $T_{1\cdot1}$ will behave in the same way, that is, in the second space interval into the body, the temperature will rise by 0.05 of the potential value at $\tau = 1.\Delta\tau$. Thus, at the end of interval 2, the temperature rise at position 2 will be $f[f(T_s - T_0)]$. Geometrically this means simply that by taking the ordinate $T_s - T_0$ we plot $f(T_s - T_0)$ at ϕ 1.δ, $f^2(T_s - T_0)$ at 2δ, and label each point with its appropriate 'm', *viz.*, 1, 2, 3, etc. The full line curve is as indicated (here $f = 0.5$ to magnify the effect). By choosing different 'f', curves of constant f can be made and labelled with the corresponding times. By joining up points of the same time designation an estimate of the temperature profile following a sudden change of temperature at the surface should be obtained. This curve could then be used to start for the method previously described.

The above procedure is only justified while the temperature gradient to the right of a given location is small.

Heat transfer to fluids

In the most common case heat flows from a solid wall to a fluid. For the preliminary discussion a heating surface of constant temperature T_s will be considered to be in contact with liquid.

If the operation of heating were conducted 'batchwise', with the fluid static and 'rigid' in the sense that heat only permeated it by pure conduction, then the unsteady state approach used for heat flow in solids could be used for the temperature history of the fluids. The time taken for a given quantity of heat to enter the fluid could be obtained by plotting the fluid surface temperature gradient against time and measuring the area under the curve. This area in conjunction with k and A permits the calculation of the heat input H in total time, assuming no heat were removed from any other surface of the fluid.

Imagine that, after a period $\Delta\tau_h$ of heating, a period $\Delta\tau_m$ of mixing is necessary (no further heating during $\Delta\tau_m$) to homogenise the liquid. Now repeat the two processes. The effect of progressively shortening the time

necessary for homogenisation should be to result in a given amount of heat being transferred in a shorter time.

If $(\partial T_f/\partial x)$ be the temperature gradient of the fluid at its surface, at the nth application of heat, then the total heat input (H) during N applications of heat, each of time $\Delta\tau_h$, is

$$H = k_f A \sum_{n=1}^{n=N} \left(\frac{dT_f}{dx}\right) . \Delta\tau_h$$

If the time $\Delta\tau_m$ for mixing between heating is constant, the total time for the change from true mean temperature T_{f1} to T_{f2} is $\tau = N(\Delta\tau_h + \Delta\tau_m)$, giving a mean rate of heat input

$$\left(\frac{H}{\tau}\right) = \frac{W . C (T_{f2} - T_{f1})}{\tau} = k_f A \sum_{n=1}^{n=N} \frac{(dT_f/dx)\Delta\tau_h}{N(\Delta\tau_h + \Delta\tau_m)}$$

On the hypothesis that the rate of heat transfer through the surface of the fluid is proportional to $T_s - T_f$ and to the heating surface area A, it can be shown that:

$$\frac{H}{\tau} = h . A \frac{T_{f2} - T_{f1}}{\log(T_s - T_{f1}/T_s - T_{f2})}$$

where the constant of proportionality is h and is called 'the heat-transfer coefficient' for the liquid surface. We have, on the hypothesis above, to find the proper values of $\Delta\tau_h$ (and hence N) and $\Delta\tau_m$ so that

$$\frac{k_f \sum_{1}^{N} (dT_f/dx) . \Delta\tau_h}{N(\Delta\tau_h + \Delta\tau_m)\dfrac{(T_{f2} - T_{f1})}{\log_e(T_s - T_{f1}/T_s - T_{f2})}} = h_{observed}$$

The method of evaluating (dT_f/dx) might be that suggested at the end of the section on 'graphical' solution for various $\Delta\tau_h$ and hence for various N.

Assuming that $\Delta\tau_m$ could, by judicious application of stirring be made to approach zero, the point of interest seems to be the evaluation of

$$\sum_{1}^{N} \frac{(dT_f/dx)}{N}$$

as $N \to \infty$, *i.e.* the mean surface temperature gradient, when working between the limits set by T_s and T_{f1}, T_{f2}. This also suggests that there is an upper limit to the effect of stirring on heat-transfer rates (allowing for heats of stirring, of course), and that the upper limit is governed by molecular processes in the vicinity of the common boundary of the solid and liquid. A similar effect has been observed in mass-transfer experiments at constant surface area. In batchwise heating processes, the effect of stirring is usually accounted for by an equation expressing the interdependence of the Nusselt, Prandtl, viscosity ratio and modified Reynolds numbers for the heating system (Perry, 'Handbook for Chemical Engineers', 1950, p. 474). The significance of these numbers will be explained in a later article. The equation

$$N_{Nu} \times (N_{Pr})^{-\frac{1}{3}} (N_{(\mu)})^{0.14} = \alpha(N_{mRe})^m$$

where n is from 0.62 to 0.667, said to be valid for $N_{mRe} = 3 \times 10^2$ to 4×10^5, does not suggest any limit to the effect of stirrer speed.

Fluids moving inside tubes

It might be supposed that a fluid in rod form could slip through a hollow tube just fitting it, and gain heat by pure conduction from the hot pipe surface (uniformly at T_s). By solving the unsteady-state equation of heat transfer for a similar rod of considerable length, initially at T_0 and with surface kept at T_s from time zero, it would be possible to prepare the graph of surface temperature gradient as a function of time for, by symmetry, this gradient would be the same at all surface positions away from the ends, at a given moment. Now consider the velocity of travel of the rod past the heating surface. This must be known from the volume rate of flow and the tube's cross-sectional area. Hence the time for any point on the moving rod to traverse the length of the heater L is $L/V = \tau$. Thus $2\pi r k_f \times$ the area under the temperature gradient curve from $\tau = 0$ to $\tau = L/V$ gives the total heat transferred in unit time, if the τ axis is now calibrated as distance along the rod. For area under curve

$$= \int_o^L \left(\frac{dT}{dx}\right)_s dL$$

so

$$k_f 2\pi r \int_o^L \left(\frac{dT}{dx}\right)_s dL \equiv k_f 2\pi r . L\left(\frac{dT}{dx}\right)_{mean} = k_f A \left(\frac{dT}{dx}\right)_{mean}$$

Graetz has obtained an analytical solution to this problem. The method outlined above is similar to that which is applicable to the performance of a continuous rotary filter or to a rotating drum cooler-solidifier, performing rather like a rotary filter. The heating of certain non-Newtonian fluids may follow this principle.

Streamline or viscous flow

Because the inner parts of the fluid usually move faster along the rod than do the outer parts, the temperature distribution in a given cross-section of the tube will differ from that for the rod in unsteady-state heat transfer at the corresponding mean time of exposure. Thus for a given overall flow rate the outer portions will spend a longer time in the tube and the inner portions a shorter time than the fluid in solid rod line flow spent. The differential equation with the movement term in it must now be used, the velocity w_r of flow at a given radius being used.

The velocity w_r at a given radius r can be calculated for viscous flow, from the mean velocity (volume rate/cross-sectional area $= \bar{w}$) in a tube of radius 'a' by the formula

$$w_r = 2\left(\frac{a^2 - r^2}{a^2}\right)\bar{w}$$

(see Lamb, 'Hydrodynamics', Cambridge University Press, p.585, for background theory).

Thus the equation relating temperature, time and position must be derived from:

$$\frac{\partial T}{\partial \tau} = \alpha^2\left(\frac{\partial^2 T}{\partial z^2} + \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) - 2\left(\frac{a^2 - r^2}{a^2}\right)\bar{w} . \frac{\partial T}{\partial z}$$

Here again if $(\partial T/\partial r)_{r=a}$ can be evaluated as $f(z)$ then the total rate of heat input can be calculated as before. At first, it could be assumed that $\partial^2 T/\partial z^2$ was negligible. Graetz has obtained a solution (see 'Jakob', **1**, 451-464).

An alternative approach is as follows.

In viscous flow it may be taken that $T_s - T_f = A(a - r) + B(a - r)^2 + C(a - r)^3$ or changing variable $v = Ay + By^2 + Cy^3$ while, for a stationary cylinder conducting heat at a steady rate radially, we have

$$\left(\frac{\partial^2 T}{\partial r^2}\right)_{a=r} = \frac{-1}{r}\left(\frac{\partial T}{\partial r}\right)_{a=r} \quad \text{or} \quad \left(\frac{\partial^2 T}{\partial y^2}\right)_a = \frac{+1}{a}\left(\frac{\partial T}{\partial y}\right)_a$$

while at the centre $(\partial T/\partial y) = 0$, $V = 0$, so

$$\frac{V}{\theta} = \frac{6}{5}\frac{y}{a} + \frac{3}{5}\left(\frac{y}{a}\right)^2 - \frac{4}{5}\left(\frac{y}{a}\right)^3$$

giving the heat flow per unit area of wall

$$q = -k\left(\frac{dV}{dy}\right)_a = \frac{6}{5}\,k\,\frac{\theta}{a}$$

following Eckert's 'Introduction to Heat and Mass Transfer', p. 98.

Since one usually designs heaters to produce at certain bulk or true mean temperature T_B rather than a central ($r = 0$) temperature of $T_s - \theta$, a relationship between $T_s - T_B$ and $T_s - T_{f(r=0)}$ is found by an averaging process which takes into account the relationships between w and $\bar{w}$ and the temperature profile across a given section. This gives $T_s - T_B = 0.583[T_s - T_{f(r=0)}] = 0.583\theta$. Since h, the heat-transfer coefficient, can be defined for a particular value of z as $q = h(T_s - T_B) = h(0.583)\theta$ we have from our previous equation for q,

$$\frac{6}{5}\,h\,\frac{\theta}{a} = h\,.\,0.583\theta \quad \text{or} \quad h = 4.12\,\frac{k}{2a}$$

where k is the thermal conductivity of the fluid and $2a$ the diameter of the tube. This approach agrees with the full solution suggested previously and obtained by Graetz.

Turbulent flow

As the value of $\bar{w} \to 0$ the viscous type of flow may taken place in smooth tubes, but as $\bar{w} >> 0$ the paths of minute particles of fluid are no longer rectilinear in pipes or in certain neighbourhoods of relatively static solid surfaces (this assumption of rectilinearity may only be true for times during which the identity of the particles containing millions of molecules is not greatly affected by the processes of diffusion due to thermal motion of the molecules).

Any protrusion down to those of atomic dimensions from the wall of the tube must be the source of extra radial components of velocity when hit by molecules with hitherto pure axial components of velocity. At low velocities these new radial components presumably are small enough to be 'lost' in the thermal motions or damped out by, or to generate, viscous forces as it is sometimes expressed. It seems that at higher velocities for a given fluid there comes a stage at which these surface disturbances, instead of dying out, start a 'chain' of other disturbances—as though a kind of resonance phenomena begins, which is able to absorb $\frac{1}{2}mw^2$ from the remaining stream and convert it to $\frac{1}{2}mv^2$ and $\frac{1}{2}mu^2$. Under certain circumstances, this zone of chaos may be so strong that it can exist for a certain time away from the wall at which it began and the shortest path from the zone of chaos to the wall may go through a quiet region of fluid. The region in which the solid-fluid boundary disturbances (drags) affect the flow pattern of the fluid is called the boundary layer and the last phenomenon described is referred to as the separation of the boundary layer from the solid surface. It is important to realise that the rod-like flow of a fluid is almost realisable at sufficient distances from a relatively stationary solid surface.

In smooth pipes free from vibrations, the viscous régime of flow, in which

$$w_r = \frac{2(a^2 - r^2)}{a^2}\bar{w}$$

gives way to another régime, even for the least viscous materials (*e.g.* gases) when the ratio of the product 'density × mean linear velocity × diameter of tube' to the viscosity of the fluid exceeds 2,300 (provided all these quantities are represented by numbers peculiar to the foot, pound, second system or to another system used for all the quantities). One curve that approximately fits the observations is

$$w_r = \frac{\bar{w}}{0.82}\left(\frac{a - r}{a}\right)^{\frac{1}{7}}$$

In the case of viscous flow, the 'Poiseuille' law, already given, follows from the hypothesis (i) that there is a proportionality between drag force (tangential) per unit area and the velocity gradient dw/dr, *viz.* $F_w = \mu A_r(dw/dr)$, where μ = viscosity = constant; (ii) that the fluid touching the wall is stationary. Of course, the two expressions for w_r given only hold for those portions of the tube sufficiently far from the tube entrance that the supposedly rod-like flow, *i.e.* $(dw/dr) = 0$, existing before the fluid entered the tube, has been modified to give a velocity profile which does not vary with z. This is supposed to be achieved when the boundary layer started at radius a, $\theta = 0$, $z = 0$, has thickened with increasing z until it meets the layer started at radius a, $\theta = \pi$, $z = 0$. Thus the hypotheses are inadequate for turbulent flow. One, leaning heavily on the viscous hypothesis, is $F_w = (\mu + \varepsilon)A_r(dw/dr)$, where ε is a function of flow conditions and called 'eddy viscosity'. This gives an unnecessary sanctity to the viscosity concept as the governing factor. It would seem that in the limit the new hypothesis needs to embrace the old, and might take cognizance of the effects not only of dw/dr but of d^2w/dr^2 and d^3w/dr^3, and also that under certain circumstances in pipes $(dp/dz) \propto \bar{w}$ and under others $(dp/dz) \propto \bar{w}^2$, where p is the pressure of the fluid.

For instance,

$$F = A_r\left[\mu\left(\frac{dw}{dr}\right) + \beta\left(\frac{d^2w}{dr^2}\right)\right]$$

might be of wider application with $w = 0$, $r = a$, where $\beta = f(r, w, \text{fluid})$ and $(dw/dr) = 0$ at $r = 0$. To embrace rod-like flow as another limit (where it is sometimes supposed that viscosity itself is a function of dw/dr) would call for other terms. Thus we have to solve

$$\frac{\partial T}{\partial \tau} \simeq \alpha^2\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) - \left(\frac{a - r}{a}\right)^{\frac{1}{7}}\frac{dT}{dz}$$

The heat-transfer problems can be solved if there is a knowledge of dT/dr as $f(z)$.

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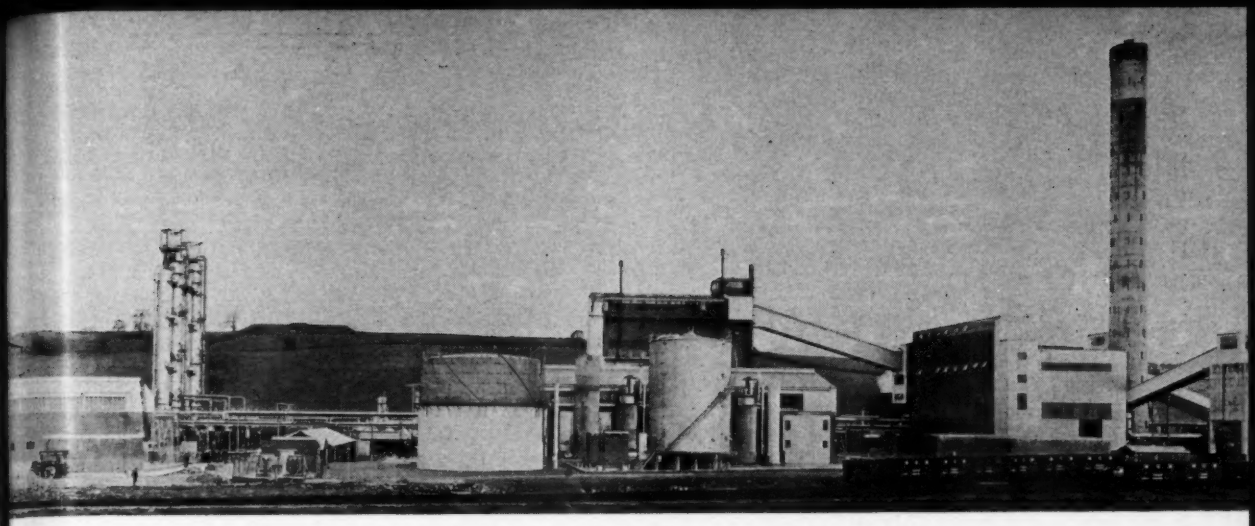


Panoramic view of Westfield Works showing Benfield tower, oxygen plant and Lurgi house

Britain's First High-pressure Gasification Plant

The Westfield works, which the Scottish Gas Board have recently built at a cost of £6.6 million, is the first plant in Britain to utilise the Lurgi high-pressure gasification system. It therefore represents a new era in gas manufacture. This article describes several chemical engineering aspects of this plant.

THE Lurgi high-pressure gasification process for the production of town gas recently came into operation in Westfield, Fifeshire. This gasification represents a radical departure from traditional gas-making processes and presages a new era of chemical engineering within the gas industry. It would not be exaggerated to claim that, in its entirety, Westfield is one of the best-designed chemical process plants in the United Kingdom comprising, apart from the Lurgi gasifiers, a variety of process units each dealing with different stages of gas manufacture: high-pressure steam production, tonnage oxygen production, carbon dioxide and hydrogen sulphide absorption, gas purification, gas enrichment and a number of ancillary processes such as benzole removal, treatment of waste gases, etc. Overall credit for commissioning and erection of the works must go to Humphreys & Glasgow, who acted as contractors for the Scottish Gas Board.

One of the outstanding advantages of the Lurgi technique is that gas is produced at such high pressure that it can be readily distributed through pipelines over long distances without using compressors along the route. The pipeline for carrying the gas from Westfield to local grid systems round Glasgow in the west and Perth and Dundee in the north, is designed for a maximum working pressure of 300 p.s.i. Westfield is already producing 15 million cu.ft./day of gas.

In view of the fact that this works incorporates many important process units of chemical engineering interest, a detailed description of the processes involved will here be given.

Coal used

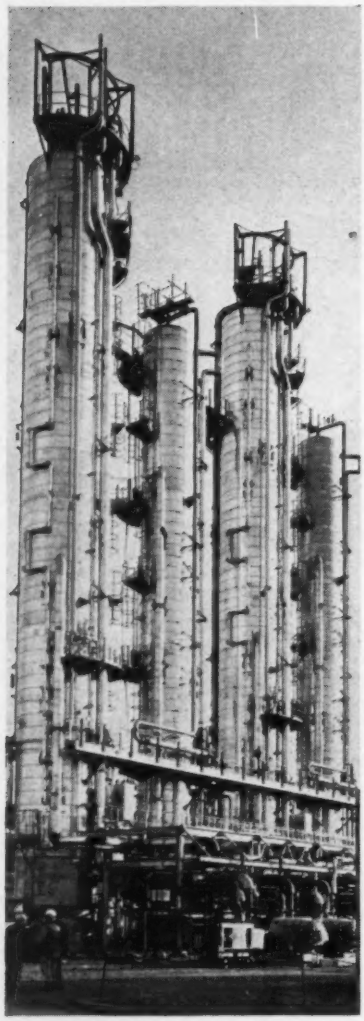
One of the economic attractions of Lurgi gasification is the fact that low-rank, non-caking coal, which is totally unsuitable for gasification by conventional means, can be used. This represents the development of a completely new outlet for this type of fuel. An open-cast mine is located adjacent to the works and a contract between the Scottish Gas Board and the National Coal Board provides for adequate supplies of coal to be made available to Westfield for at least 20 years. The Coal Board have also built a washer and supply a mixture of washed coal $\frac{1}{2}$ in. to 1 in. to which a proportion of middlings is added. This coal is delivered to the works by railway wagon and carried by conveyor belt to the gasifiers.

Lurgi gasifiers

At present three gasifiers are in operation; each gasifier has an output of about $7\frac{1}{2}$ million cu.ft./day. of gas. The gasifier is a mild-steel vessel, 10 ft. outer diameter and 19 ft. overall height. The gasifier shell is cooled by passing water through an annular jacket. The cooling water passed into the jacket is converted to low-pressure steam which is then passed into the lower

end of the gasifier, together with the high-pressure steam and oxygen. The coal enters through a lock-hopper attached to the top of the gasifier. The gas is generated as a result of the reaction of steam and oxygen which pass upwards through the coal bed. A mechanical stirrer is fitted inside the gasifier so that weakly-caking coals can also be gasified.

Since oxygen and not air is used as the oxidising medium, no nitrogen is produced and the fuel has a higher calorific value. The amount of steam in the gasifier controls the temperature which must not be sufficiently high to melt the ash (since removal of molten slag from a pressure gasifier is still impossible at present). The ash formed is removed from the bottom by passing it into a hopper and depressurising this by circulating the steam-ash mixture through water.



'Benfield' plant for removal of CO_2 and H_2S

The raw gas leaves the top of the gasifier at a temperature of between 400° and 450°C. Tar water is sprayed into this gas in a quench cooler to reduce the temperature to 196°C. This allows fullest use to be made of the sensible heat of the gas as it passes through the waste-heat boilers (also removing tar and ammonia at this stage). The gas passes from the waste-heat boiler to a precooler and from there, in twin streams, to another installation of coolers, each stream of which consists of two vertical tubular water-cooled heat exchangers in series called the 'after-cooler' and 'final cooler'. The raw gas leaving the coolers has the following composition: H_2 40%, CO 22%, CH_4 9.3%, O_2 0.8%, N_2 0.6%, CO_2 27.5% and H_2S 0.6%. (A characteristic of high-pressure gasification is the production of a significant proportion of methane.) The carbon dioxide content must be reduced in view of its effect on the calorific value of the gas. The hydrogen sulphide content must also be reduced to conform to statutory limitations. It will be noted that the carbon monoxide content is considerably higher than in normal town gas, and a shift conversion plant is now being constructed to convert most of the CO to CO_2.

Absorption towers

After the gas leaves the coolers it passes through various stages of purification. In one stage, benzole is removed by washing with light oil. Removal of hydrogen sulphide and carbon dioxide is effected in a further stage by washing the gas with hot potassium carbonate, the CO_2 and H_2S being simultaneously absorbed by the potassium carbonate. This absorption is carried out in the *Benfield* plant consisting of two absorption and two regenerating towers. The hot gases pass into the bottom of the packed absorption tower and a split stream of potassium carbonate enters through the centre of the tower. This first stream absorbs most of the CO_2 and H_2S as potassium bicarbonate and potassium bisulphide. The second stream of potassium carbonate enters the column at the top where further amounts of CO_2 and H_2S are removed. The solution leaves the absorber and, after a reduction in pressure from 425 to 5 p.s.i., passes into the regenerator vessel where conventional steam stripping is carried out at the same temperature.

The waste gases leaving the top of the regenerator pass through two large air-cooled heat exchangers which condense and cool the waste gases. A novel feature of these units is the use of aluminium for manufacturing the finned tubes and header boxes in order to overcome the corrosion problem associated with wet CO_2 and H_2S. Each heat exchanger is designed to dissipate 3 million B.T.U./hr. at full load conditions and they are fitted with direct-driven fan units that provide a forced draught of air across the finned surface of the tube bundles. The cooled gases pass to a catalytic conversion plant where H_2S is reduced to SO_2; the gases are then mixed with boiler flue gases and finally passed through the main chimney stack.

Final H_2S removal

Only 90% of the CO_2 and H_2S are removed in the *Benfield* plant; it is therefore necessary to add a further purification stage to remove the final traces of H_2S. The *Bischoff* system of oxide purification has been selected for this final removal. The Westfield plant comprises two parallel streams, each of four high-pressure purifiers, designed for operation at 340 p.s.i.—each purifier and one of two stacking towers is provided with 12 trays containing hydrated iron oxide. The system operates on the principle that the oxide is removed in rotation from one tower to another at specific intervals, the towers themselves always remaining in the fixed rotation order of 1, 2, 3 and 4. Normally both streams will be in action, but when it becomes necessary to renew the iron oxide, one stream is completely shut off leaving the other stream to carry the load temporarily. The towers in the stream which has been shut off are then opened, the oxide trays in tower 1 are removed and placed in the empty stacking tower; the trays in 2, 3 and 4 are moved back to 1, 2 and 3 and finally new trays containing a mixture of revivified and new oxide are placed in tower 4. The fouled oxide placed in the stacking tower is then removed for revivification.

Enrichment

The gas which has been produced and purified by the above-mentioned processes is 'conditioned' so that its calorific value and specific gravity correspond to town gas requirements, *viz.* 450 B.T.U./cu.ft. and 0.55 respectively. The purified gas has only a calorific value of 400 B.T.U./cu.ft. and therefore it is enriched with commercial butane which is brought to Westfield by road from Grangemouth

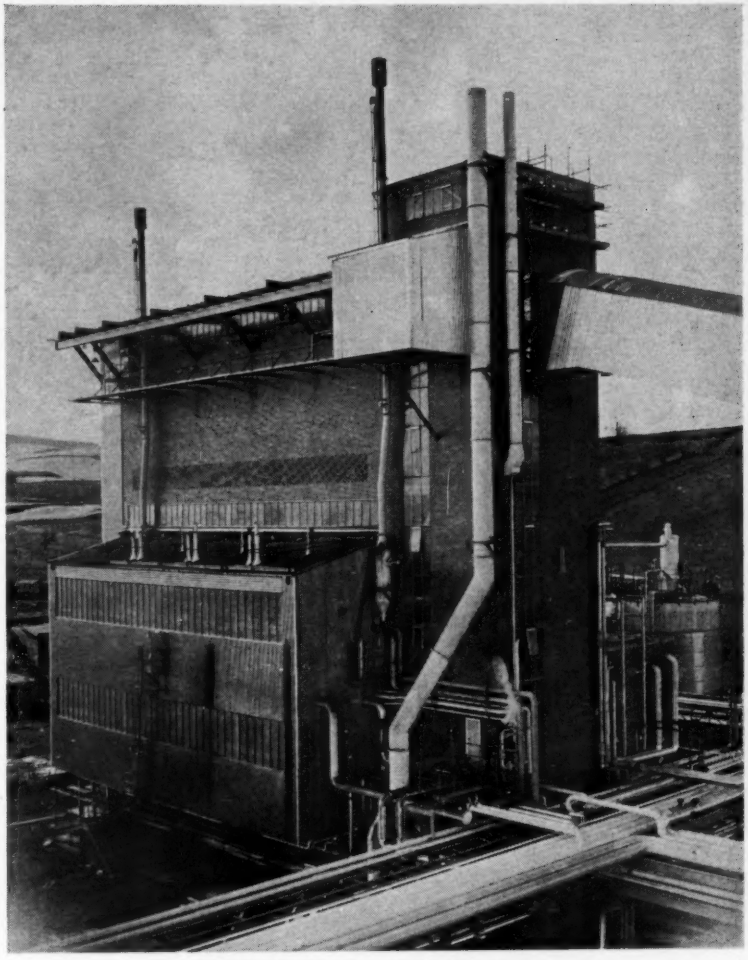
oil refinery, 35 miles from Westfield. At present the butane storage at Westfield consists of three 56-ton-capacity horizontal cylindrical tanks. A new spherical butane storage tank of 500 tons capacity is now under construction. It will meet increased requirements for butane when stage two comes into operation. The proportion of butane in the final gas is about 2%.

Steam boiler

The boilers supplying high-pressure steam to the gasifiers are fired by the *Ignafluid* method, developed by Babcock & Wilcox Ltd. The fuel used for steam raising is high-volatile, weakly caking coal crushed to below $\frac{1}{4}$ in. before being delivered to the boiler house bunkers. The fine coal is introduced into the boiler furnace by a vibratory feeder and cascades on to a fuel bed that is maintained in a state of fluidisation by means of pulsated air steams injected below the narrow chain grate. This grate, which is upwards inclined towards the rear of the furnace and which travels from front to rear at a relatively high speed, can be regarded solely as an ash carrier.

Some of the coal is burned in suspension, the remainder burning on the sloping sides of the fuel bed between the boiler side walls and the grate. Semi-molten ash flows by gravity down these sloping sides to the bottom of the fuel bed and is conveyed as clinker to the rear of the furnace, where it is discharged to a suitable ash-removal plant. Primary air from the forced-draught fan is fed to compartments below the upper stand of the grate. These compartments are equipped with dampers provided for a decreasing air-pressure gradient from front to rear of the stoker. By means of a motor-driven disc valve in the forced-draught fan outlet, the primary air flow through the grate can be pulsated to produce continuous fluidisation of the fuel bed at variable frequency.

This pulsation prevents segregation of the coarse and fine fuel particles, thus improving combustion. Furnace maintenance is therefore reduced to a minimum, since the lower parts of the furnace are well protected by the thick sloping banks of fuel at each side and below the fuel port. Since the moving grate occupies only a small area of the furnace floor, it is also protected from thermal stresses by the thickness of the fluidised fuel/ash bed and by the cooling effect of the primary air streams, hence its availability is high and maintenance very low.



Lurgi house where three gasifiers are situated

Tonnage oxygen plants

Two tonnage oxygen plants, each with a capacity of 100 tons/day, have been designed and built by the British Oxygen Co. Ltd. The tonnage process consists of cooling the air, partially liquefying it and distilling liquid air to separate oxygen from nitrogen. Air is first filtered to remove dust, then compressed in a turbo-compressor to about 75 p.s.i. The heat of compression is removed by directly cooling the compressed water. The cooled air is then divided into two streams, the smaller of which is further compressed to about 2,000 p.s.i. and purified from moisture and carbon dioxide. The larger stream is cooled almost to liquefaction in one of the two regenerators packed with stones which are periodically cooled down by warming the outgoing nitrogen. As this cooling takes place, moisture and CO_2 are frozen out on the packing and removed when outgoing product nitrogen returns through the regenerator.

The high-pressure stream is also cooled in a separate system of heat exchangers partly by the outgoing oxygen which is thereby vaporised under pressure and warmed to atmospheric temperature, and partly by some of the nitrogen which is also warmed up. A portion of the high-pressure air is withdrawn at about –20°C. through an expansion engine to the same pressure (72 p.s.i.) as the remaining low-pressure air. The remainder is cooled almost to dewpoint and expanded through a valve to the same pressure. Thus about 30% of the total air is liquefied. The combined air streams (liquid and vapour) then enter the distillation column system which consists of two columns, one above the other, connected by a condenser.

The lower part of this column operating at 70 p.s.i. is fitted with

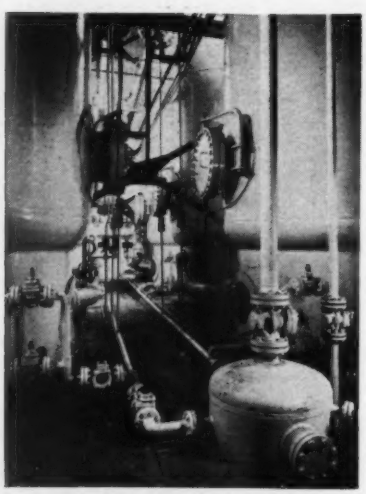
a scrubbing section to remove residual impurities which are filtered off from the oxygen-rich liquid collecting at the base. This liquid passes through a sub-cooler before entering the upper column as feed. In this column nitrogen is condensed at lower column pressure by liquid oxygen boiling in the sump of the upper column. The liquid nitrogen produced serves as reflux for the top of both columns. The nitrogen fraction is withdrawn from the top of the upper column and is passed through the sub-coolers before leaving the air separation plant through the regenerators and heat-exchanger system.

The liquid oxygen is delivered under pressure by a pump through the heat exchanger, in which it is evaporated under pressure and warmed to atmospheric temperature. The nitrogen is also warmed up as it leaves the plant, partly by cooling some of the high-pressure air and partly by cooling the packing on one or other of the regenerators which serve to cool the bulk of the incoming low-pressure air. A special feature of the design is that gaseous oxygen is produced directly from the plant at the pressure (425 p.s.i.) required for the gasifier.

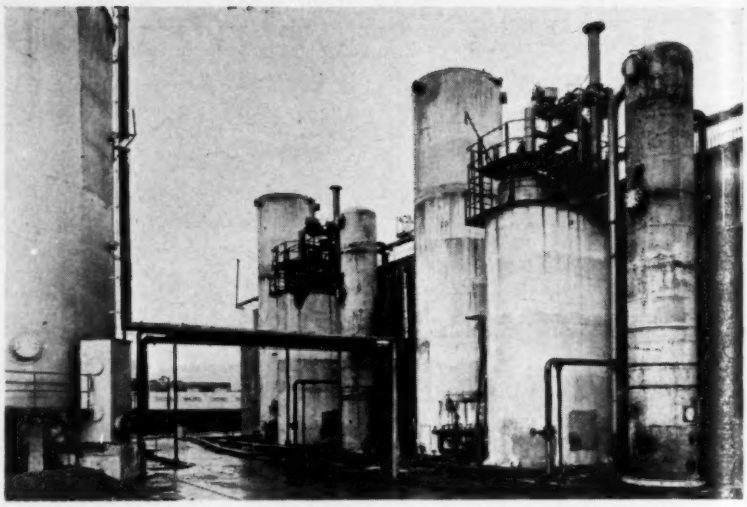
The plant is also designed to produce up to 10% of the rated output as liquid oxygen which can be stored in a 550-ton-capacity insulated tank to form a readily available reserve to cover peak periods.

Supergrid

The Scottish national supergrid, as at present contemplated, comprises some 260 miles of mild-steel high-pressure pipeline, ranging in size from 12 to 2 in. diam. The techniques used in pipeline construction are similar to those developed for long-distance cross-country oil and natural gas pipelines in the U.S. and the Middle East (see CPE, 1961, **42**, 203). When finally completed, the total length of grid mains within the area of the Scottish Gas Board will be in the order of 1,100 miles and will thus constitute a national gas grid for Scotland.



Final H_2S purification plant



Tonnage oxygen plant, showing air-separation unit regenerator and direct cooler

In many ways this has been a unique project; there was little precedent (especially in this country) for the assembly of the component process plants, although the principle of the Lurgi process itself has been employed elsewhere. In order to achieve the best design, teams of engineers were sent abroad to technical organisations and manufacturing plants in order to negotiate the optimum process for a particular duty.

The commissioning of Westfield was carried out in an astonishingly short space of time. Coal was fed to the gasifiers on December 22, 1960, and gas was first fed to the grid five days later.

In fact, the plant was started up ahead of the contracted date and its service to Scotland began earlier than was thought likely. This fact is sufficient evidence of the successful co-ordination of the project and to the efforts of all who helped in it—designers, manufacturers, inspectors and administrators.

Second stage

As has been pointed out, the Westfield works is being constructed in two stages. During the second stage, which is now in progress, the fourth Lurgi gasifier, constructed by Ashmore, Benson, Pease & Co., will be installed together with a newly developed plant for the reduction of the CO content of the gas. A further steam boiler of the *Ignafluid* type, and sulphur-recovery plant for the removal of sulphur from the waste gases, will also be introduced.

The principal effect of these further developments will be that the total production of gas will be doubled. The effect of the carbon monoxide conversion plant will be to reduce the CO content of the gas to less than 8%; it will also help to reduce the specific gravity of the final gas. The CO conversion plant will be installed at the outlet of the waste-heat boiler and will treat hot, crude Lurgi gas at a temperature of approximately 105°C. This will be the first 'raw gas conversion plant', as it is called, to be installed outside Germany.

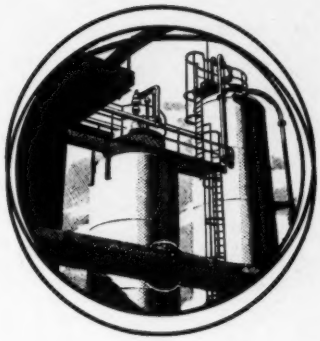
Reactor symposium

The Institute of Physics and the Physical Society announce that in collaboration with the British Nuclear Energy Conference it is sponsoring a symposium on 'The Physics of Graphite-moderated Reactors', to be held in Bournemouth, April 4-6, 1962.

Postgraduate course scheme

The Institution of Chemical Engineers has produced a pamphlet entitled 'Scheme for a Postgraduate Course in Chemical Engineering'. The growth of postgraduate courses slackened after World War II with the development of the primary degree course, but many companies prefer men who have qualified first in chemistry or mechanical engineering.

Materials of Construction for Chemical Plant



SILVER

By J. A. Stevenson,* B.Sc.

This article, discussing the applications of silver and its alloys as materials of construction for chemical plant, is the fifteenth in this series. Previous articles have dealt with PVC, lead, nickel, stainless steels, graphite, polyolefines, copper, timber, platinum, titanium, aluminium, reinforced plastics, cast iron and mild steel. One of the oldest constructional materials for chemical plant, silver has considerably higher cost than other materials, but it can still nevertheless be economically employed in many types of plant.

SILVER has been employed for many years in equipment for the processing of chemicals and foodstuffs and, although a considerable number of corrosion-resistant materials are now available, its use is continually being extended. The properties which attract the designers' attention include its high resistance to corrosion over a wide range of chemical conditions, from strong caustic alkalis to concentrated mineral acids. The thermal and electrical conductivities are higher than those of any other metal and silver is readily available with a purity of not less than 99.99%.

Silver occurs in three main forms: native, as a sulphide, or in combination with the ores of lead, copper or zinc. Native silver has been known since the very earliest times and it is found almost universally. Old world supplies of native silver were quickly exhausted and new sources were found in Canada, Mexico and Peru. Today these are becoming depleted, and silver is now obtained from sulphide ores at Broken Hill (New South Wales), Sudbury (Canada), and in Nevada and British Columbia. There is, of course, a great amount of the metal in constant circulation, and silver is refined from industrial and jewellers' scrap as well as from demonetised coinage metal.

After mining, the ores are first dressed and then converted to rough bullion ready for final refining. Native silver is simply concentrated and cast into ingots. The sulphide ores are leached with cyanide to produce a silver cyanide solution from which silver can be displaced and cast into ingots. The base-metal ores containing silver are smelted in blast or reverberatory furnace to produce a low-grade matte which is then treated to produce rough bullion.

Refining

This impure silver is next passed to the refinery where the main contaminants, gold, copper, lead, zinc, selenium, tellurium, and other base metals, are removed. The impure bullion is treated by the cupellation process where it is melted down with lead, and air is blown over the surface of the molten metal. The molten lead oxide dissolves all the other base-metal oxides and forms a layer on the top of the bath which can be run off to leave silver of about 98% purity. This is then cast into anodes for electrolytic refining to yield metal of not less than 99.9% purity. A second electrolytic refining can improve the purity to 99.99%.

In addition to the newly mined silver, most refiners handle a steady flow of secondary or scrap silver in many forms and conditions. These may range from the complete coinage of a country that has decided to demonetise its silver to industrial scrap and waste from metal-working operations.

Fig. 1

Clean metallic scrap is refined in the same way as native silver, but low-grade scrap and residues are first smelted to yield a lead bullion and subsequently refined by cupellation

*Johnson Matthey & Co. Ltd.

and electro-deposition. Fig. 1 shows a large silver ingot which is ready for further fabrication.

Physical properties

The principal physical properties of pure silver are set out in Table 1. It has an atomic weight of 107.88 and an atomic number of 47. In the periodic classification of elements it is in Group IB between copper and gold, and at the beginning of the latter half of the second long period, where it falls between palladium and cadmium. The thermal conductivity is 1.00 cal./cm.sec.°C. at 0°C., compared with a figure of 0.94 for copper. This high thermal conductivity gives excellent heat-transfer characteristics for solid silver or silver-lined chemical plant. The electrical resistivity, 1.6 microhm-cm., is the lowest value of any metal and corresponds with a conductivity of 106% of the International Annealed Copper Standard. These high values of electrical and thermal conductivities coupled with corrosion resistance are the major reasons for the widespread use of silver as a contact material.

Mechanical properties

Annealed silver is soft and easily deformed, its tensile strength being approximately 9 tons/sq.in. Cold working can increase this value to about 20 tons/sq.in. with a Vickers hardness of 95 to 100 against 26 in the annealed state. The effect of progressive reductions in thickness by cold rolling is shown in Fig. 2. The tensile properties at elevated temperatures are shown in Fig. 3. It is possible by alloying to improve the mechanical properties of pure silver, and this will be discussed later.

Table 1. Physical properties of silver

Specific gravity	10.5
Melting point, °C.	960.8
Thermal conductivity, c.g.s. units	1.00
Coefficient of linear expansion (0° to 100°C.) per °C.	0.000019
Specific heat, cal./gm./°C. at 20°C.	0.056
Latent heat of fusion, gm. cal.	24.9
Resistivity, microhms/cm. cube at 20°C.	1.6
Temperature coefficient of resistance (0° to 100°C.) per °C.	0.0041
Tensile strength, tons/sq.in. (annealed)	9
Elongation, % (annealed)	60
Modulus of elasticity in tension, p.s.i.	10.3×10^6
Modulus of elasticity in torsion, p.s.i.	3.9×10^6
Vickers hardness (annealed)	26

Chemical properties

Silver has a high place in the electrode potential series, having a standard potential of 0.8 V. This high positive potential is the principal reason for its excellent resistance to corrosion. The formation of a protective film is of secondary importance, although it is the controlling factor in the resistance of silver to halides and halogen acids.

Silver has high resistance to most dilute mineral acids, either hot or cold. It is resistant to sulphuric acid, except when the concentration is above 80% and the acid is hot. It can also resist hydrochloric acid at low concentrations and temperatures in the absence of air. Hydrofluoric acid does not attack silver appreciably and the metal shows effective resistance to phosphoric acid. However, it is readily attacked by nitric acid at all concentrations. The resistance to hot or cold organic acids is extremely good.

Alkaline solutions and fused alkalis have no effect on silver even when at quite high temperatures. It is completely resistant to a great number of salt solutions, but is rapidly attacked by cyanides. Silver does not oxidise in air even up to the melting point, although on normal exposure it quickly forms a tarnish film of silver sulphide. Table 2 gives more specific information upon the corrosion resistance.

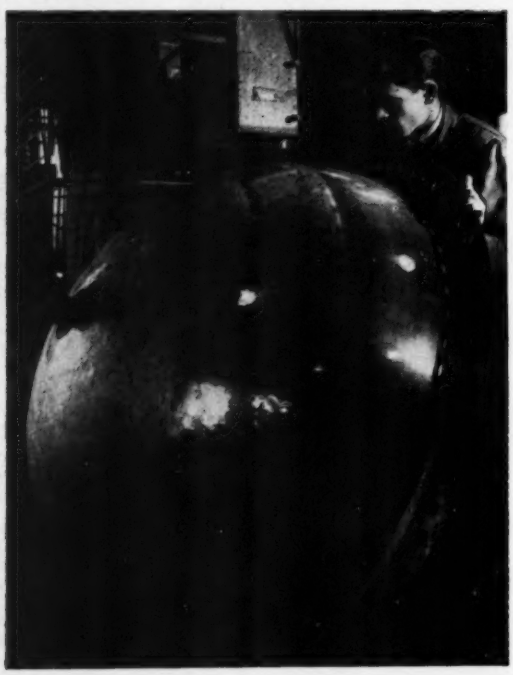


Fig. 5. A large, solid-silver still-base in manufacture

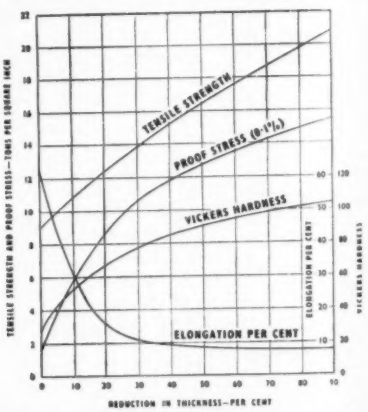


Fig. 2. Effect of increased amount of cold rolling on the mechanical properties of silver

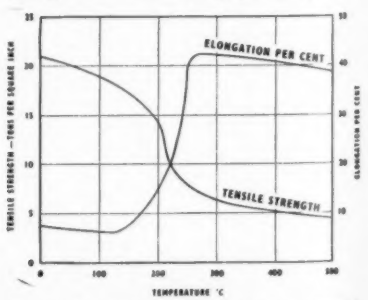


Fig. 3. Tensile properties of silver at elevated temperatures

Principal alloys of silver

While pure silver has a number of established uses, its lack of mechanical strength and its liability to sulphide tarnishing has prompted the use of silver alloys which, while retaining the desirable properties and ease of fabrication of the parent metal, give improved hardness, strength and resistance to wear. In some cases there is an improvement in the resistance to tarnishing. The principal commercial alloys are the binary alloys with copper, gold and palladium, respectively, and the effect of additions of these elements on the Vickers hardness number is shown in Fig. 4.

Of the metals normally alloyed with silver, copper not only is among the most effective in improving hardness and wear resistance, but also has little effect upon the electrical and thermal conductivities. However, resistance to tarnish and corrosion diminishes with increasing copper content. The usual commercial alloys are those containing 7.5% copper (standard or sterling silver), 10% and 20%. The 7.5% copper alloy can be hardened by quenching and tempering.

Additions of gold have little effect on hardness and the improvement in resistance to tarnish is slight. However, there is some reduction in the rate of tarnishing, although complete freedom from sulphide film formation is not obtained unless over 50% of gold is present.

The palladium-silver alloys normally employed contain 5%, 10% and 20% of palladium and, as with gold-silver, some improvement in tarnish resistance is obtained. These alloys are cheaper than gold-silver and also show advantages in terms of hardness and wear resistance.

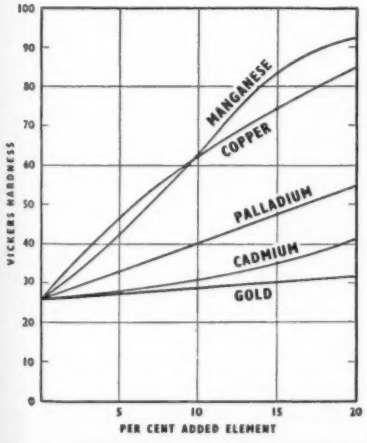


Fig. 4. Effect of alloying elements on the Vickers hardness of silver alloys

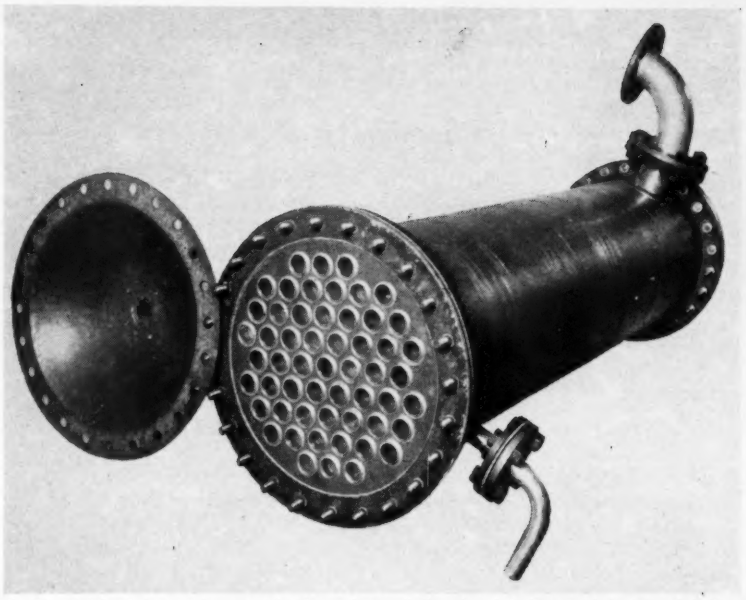


Fig. 7. Multi-tubular condenser with silver tubes and silver-lined shell, provided with solid-silver inlet and outlet connections

Cadmium-silver alloys have been developed for specialised electrical contact applications and some improvement in resistance to sulphide tarnishing can be obtained.

Manganese has a very marked effect on the hardness and other mechanical properties of silver, but there is a very sharp decrease in electrical and thermal conductivities. For example, 15% manganese-silver alloy has an electrical conductivity of only 4.5% IACS.

Silver brazing alloys

One of the major uses of silver in alloyed form is in the well-known low-temperature silver brazing alloys. These materials have melting points ranging down to 630°C., possess greater fluidity than the normal brazing spelters and show an improvement in strength, ductility and ability to make sounder and stronger joints. There is an extensive range of these alloys suitable for making joints on ferrous or non-ferrous metals which melt at not less than 700°C. The alloys consist essentially of silver-copper-zinc or silver-phosphorus-copper. Other additions are often made to improve specific qualities.

Plant construction methods

Because of its relatively high initial cost and low mechanical strength, silver is usually employed as a lining for vessels made of copper, nickel or mild steel. Generally the linings are about $\frac{1}{32}$ in. thick and, if possible, are bonded to the outer vessel. This bonding ensures good heat-transfer characteristics and prevents the liner collapsing under the influence of vacuum or due to creep stresses. In a very thick-wall vessel, such as a high-pressure autoclave, bonding is not practicable and it is usual to make the liner slightly oversized and to press it into place so that there is an intimate contact between silver and base metal. In equipment with bonded linings the temperature must not exceed 200°C., but vessels with loose liners may be used at higher temperatures. Very large vessels are readily lined with silver produced in sheet form, seams

Fig. 6. Silver two-start condensing coil

being made by fusion welding. Silver is extremely ductile and can be easily formed over complex sections or flanges.

Solid silver is mainly used for tubes or thin-wall structures with low stresses. Fig. 5 shows a hemispherical pan under construction which will form the base of an oil-heated vacuum still for a distillation process. Fig. 6 shows a cooling coil which has a wall thickness of $\frac{1}{16}$ in. Silver can be drawn into seamless tubes with walls 0.01 in. or less, although for units such as heat exchangers the walls are generally 0.025 to 0.040 in. thick. Bi-metal tube, that is silver on copper, can be produced for coils which are used for high-pressure stills. The tube is formed from a silver/copper bi-metal sheet which is cupped and drawn. Fig. 7 shows a multi-tubular condenser, in which the header plate has a bonded silver lining and the individual tubes are spun over and brazed into position. Fig. 8 shows a mild-steel vessel with a bonded silver lining of 30-gal. capacity.

Electrodeposited silver

While bonded linings or solid silver shells offer the best resistance to corrosion, it is often impracticable because of complex shapes to use sheet silver. In addition, it would be too expensive to cover with silver larger plant components such as a centrifuge basket. In these circumstances it is possible to employ an electrodeposited layer which can be applied to most base metals.

General Applications

The first major use of silver was probably as condenser tubing and transfer piping in the condensation and handling of acetic acid. Soon after this it was adopted by the food industry because of its inertness to organic chemicals. It found uses in plant distilling vinegar, and for stills and storage tanks in the manufacture of flavouring oils. The milk, cider and brewing industries made use of silver in the form of syphons, pasteurising coils, pipelines and the nozzles of filling machines.

Nowadays silver is still used in these industries as well as in the handling of wet chlorine, acetic acid, acetic anhydride, phenol and phenolic derivatives, citric, lactic and maleic acids, and in the manufacture of pharmaceutical preparations. Stirrers, agitators and thermocouple sheaths are all parts which are fabricated from silver.

Although silver has a considerably higher unit cost than most engineering materials, it can nevertheless be economically employed in many items of plant. Because silver can be easily worked, the cost of fabrication is relatively low and, since the original value of the silver can be largely recovered when the plant is taken out of commission, the net cost of a silver-lined vessel is often less than that of a vessel made in one of the other corrosion-resistant materials.

Table 2. The resistance of silver to chemical attack

Corroding medium	*Concentration, %*	*Temperature, °C.*	*Weight loss, mg./day*	*Rate of attack, in./yr.*
Organic acids:				
Acetic acid vapour	100	118	3	0.0004
" " liquid	99.5	Boiling	3	0.0004
" " liquid-vapour junction	99.5	Boiling	5	0.0007
Citric acid	5	Boiling	10	0.0014
" "	15	100	0.3	0.00004
Cresol (crude m. & p.)	—	70	Nil	Nil
Lactic acid (24-hr. test only)	50	Boiling	150	0.02
Phenol, dry	100	Boiling	Nil	Nil
" impure	95	Boiling	15	0.002
Inorganic acids:				
Hydrochloric acid, non-aerated solutions	5	35	2	0.0003
" " "	5	100	10	0.0014
" " "	15	20	13	0.0018
" " "	25	20	30	0.004
" " "	35	20	45	0.006
" " "	35	100	700	0.1
Hydrofluoric acid	40	110	29	0.004
" "	100	38	13	0.0018
Nitric acid	All	All	Rapid attack	
Phosphoric acid	5	100	0.9	0.00012
" "	45	100	0.19	—
" "	70	100	0.63	0.0001
" "	85	100	1	0.00014
Sulphuric acid	10	Boiling	2	0.0003
" "	20	Boiling	4	0.0006
" "	60	Boiling	25	0.0035
" "	85	Boiling	Rapid attack	
Alkalis:				
Sodium hydroxide (corrosion rates are accelerated by oxidising conditions)	70	110	1	0.00014
Sodium hydroxide	Fused	400	4	0.0006
Potassium hydroxide	Fused	400	25	0.0035
Other chemicals:				
Aluminium chloride	30	100	5	0.0007
Aluminium sulphate	30	100	0.7	0.0001
Calcium fluoride	Sat. solution	100	Slight gain	—
Bromine, pure dry (specimens weighed after removal of halide film)	100	20	5	0.0007
Bromine, moist	100	20	8	0.0011
Bromine, aqueous	90	20	10	0.00135
Chlorine (specimens weighed after removal of halide film)	Gas	20	—	—
Chlorine	Gas	100	30	0.004
Sodium fluoride (aerated solution)	3	20	—	—
Sodium fluoride	Sat. solution	100	—	—

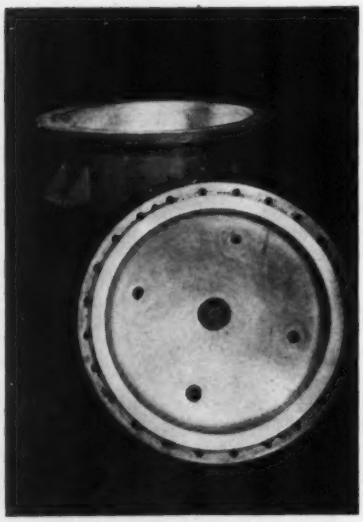


Fig. 8. 30-gal.-capacity single-shell open mild steel vessel with a bonded silver lining

The material of construction for chemical plant which will be discussed in next month's issue of CHEMICAL & PROCESS ENGINEERING will be

GLASS

Determination of Cost Estimation

By H. G. McGower

Cost estimation is a very inexact science and most companies have their own methods for determining costs. This article describes a practical method of preparing cost estimates for chemical plant, which is of sufficient accuracy for practical evaluation.

AS is known from practice, there are many items of expenditure that have to be acquired after a chemical plant has been erected, due to the fact that various items may have been overlooked in preparing preliminary cost estimates. However, such small items, individually, do not amount to a large proportion of the total cost estimate, but collectively they could lead to major inaccuracies. It would be true to claim that most cost estimates are sufficiently detailed with respect to prices of main process equipment such as pumps, compressors, distillation columns, etc., because the price of such equipment can be readily obtained from quotations, price lists or buyers' lists. Piping, on the other hand, cannot be specified in the same detail as process equipment until the plant has been completely designed. This, therefore, represents a major cost item and constitutes a serious source of error in this type of estimate. The same can be said of instrument costs, erection costs, construction tools, equipment hire and rents, general field expenses, development costs, research costs and general overheads. Details are also lacking about costs of minor items such as electrical equipment, yard paving and piling, steel structures, concrete foundations, insulation, fire proofing, painting and temporary facilities.

In each estimating method to be described, the costs of the above items for which details are lacking, have been expressed as a percentage of the main equipment costs. These percentages are average figures based on analysis of the costs of previous jobs. Because averages have been used, some cancellation of errors is achieved and the total is seldom seriously in error. These estimates are of considerable value because they are reasonably accurate and can be readily compared.

In preparing a cost estimate, several types of plants must be differentiated:

(1) Plants handling fluids and/or gases (merely outdoor construction).

Table 1

(1) *Fluids/gas processing plants*	%
Electrical	5
Steel structures	5
Instruments	15
Insulation and painting	5
Buildings and foundations	20
Piping	45
Temporary facilities and sundries	5
	100
(2) *Mixed processing plants*	%
Electrical	5
Steel structures	5
Instruments	10
Insulation and painting	5
Buildings and foundations	30
Piping	35
Temporary facilities and sundries	5
	95
(3) *Solids processing plants*	%
Electrical	10
Steel structures	5
Instruments	10
Insulation and painting	5
Buildings and foundations	35
Piping	20
Temporary facilities and sundries	5
	90

Table 2

Type of equipment	%
Blowers	8
Centrifuges	10
Columns, field fabricated	25
Columns, prefabricated	15
Compressors	8
Conveyors	10
Drums and accumulators	10
Dryers	10
Extruders	10
Ejectors	8
Filters	8
Heat exchangers and coolers	4
Pumps	4
Reactors	10
Instruments	15
Piping	80
Steel structures	25
Insulation	100
Buildings and foundations	100
Brick lining in vessels	30
Electric lighting	110
Electric power	60
Electric average	75
Temporary facilities	20

Table 3

Main process equipment	%	*f.o.b. price*	*% For erection*	*Erection costs*	
		£		£	£
Three distillation towers		10,000	25	2,500	
Five drums		5,000	10	500	
Six heat exchangers and coolers		10,000	4	400	
Six pumps with electric motors		6,000	4	240	
Two compressors, turbine driven		4,000	8	320	
Total		£35,000		£3,960	
Auxiliary equipment					
Electrical	5	1,750	75	1,310	
Steel structures	5	1,750	20	350	
Instruments	15	5,250	15	785	
Insulation and paintings	5	1,750	100	1,750	
Buildings and foundations	20	7,000	100	7,000	
Piping	45	15,750	80	12,650	
Temporary facilities and sundries	5	1,750	20	350	
Total f.o.b. price and erection		£70,000		£28,155	
Total direct costs					98,155
Total general overhead	30*				29,500
					£127,655
Contingencies	10*				12,345
Total price of the chemical plant					£140,000

* Estimated

(2) Mixed processing plants (partly indoor and outdoor construction).
(3) Plants handling solids (merely indoor construction with separate storage facilities).

After the prices of main process equipment have been determined, the minor items can be priced as a percentage of the main process equipment as shown in Table 1. After this has been done, the total f.o.b. costs of materials of construction are determined. Erection costs are then calculated and the percentages for erection are subtracted from the f.o.b. price for each item given as shown in Table 2.

From these percentages the total direct costs are determined as illustrated in Table 3 for a fluid/gas process plant.

Pumping equipment

A survey of Pumps for the Food Industry is a special feature in the July issue of **Food Manufacture.** Other articles include: Microscopical Technique—Section Cutting, by S. M. Charlett.

The following articles appearing in our associate journals may be of interest to readers of CPE.

Paint Manufacture—A series of articles on the paint industries of Australia, Canada, India, Rhodesia and South Africa.

Manufacturing Chemist — Floors for Chemical Factories, by P. A. Howden. Small-scale Manufacturing Equipment—Dryers, by Dr. H. W. Fowler. Glycerine in Adhesives, by F. N. Reckless.

Petroleum—An Evolution in Oil Exploration, by G. D. Hobson. Hassi R'Mel-Arzew Gas Pipeline: A milestone in the development of Saharan gas.

Corrosion Technology—PVC Pipes in Corrosive Conditions, by A. Trebucq.

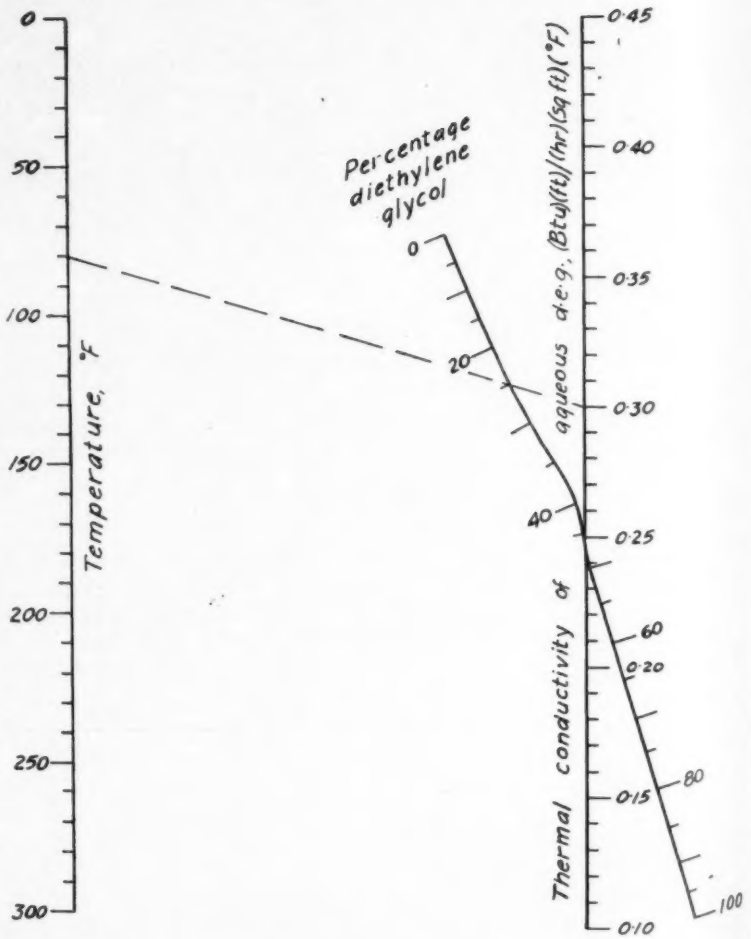
Automation Progress—The Psychology of Man and Automation, by M. Le Gros Clark. Hydraulic Control Circuits, by W. M. Morrison.

Fibres and Plastics—Analysis and Testing of Plastics, by G. C. Ives. Review of Interplas Exhibition.

Specimen copies of these journals and subscription forms are available from the Circulation Manager, Leonard Hill House, Eden Street, London, N.W.1.

Thermal Conductivity of Aqueous Diethylene Glycol

By D. S. Davis*



The accompanying line co-ordinate chart enables rapid and accurate estimation of the thermal conductivities of aqueous solutions of diethylene glycol over a wide temperature range when the concentrations are known.

The broken index line shows that the thermal conductivity of 25% diethylene glycol at 80°F. is 0.30 (B.T.U.)(ft.)/(sq.ft.)(hr.)(°F.).

Note that when the concentration is 47.5%, the thermal conductivity is 0.245 (B.T.U.)(ft.)/(sq.ft.)(hr.)(°F.) and is independent of temperature.

The chart, based on reliable data,[1] was constructed in accordance with methods described previously.[2]

REFERENCES

[1]D. L. Katz *et al.*, 'Handbook of Natural Gas Engineering', p. 603. McGraw-Hill Book Co. Inc., New York, 1959.
[2]D. S. Davis, 'Nomography and Empirical Equations', Chap. 10, Reinhold Publishing Corporation, New York, 1955; 'Chemical Processing Nomographs', Unit 1, Chemical Publishing Co. Inc., 1960.

**Head, Department of Pulp and Paper Technology, University of Alabama.*

What's New

in Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.

Cooling tower

The Head Wrightson *Fluor* Series 1 cooling tower is designed for small industrial and air-conditioning applications. It is supplied in several standard sizes. For typical applications, capacities of single-cell units range from 100,000 to 600,000 B.T.U./hr., and two or more single-cell units may be used to meet higher-capacity requirements.

The cooling tower operates on the counter-flow principle and consists of a top section containing the water distribution system, drift eliminators and fan unit; an intermediate section packed with polygrid tower fill; and a bottom section which is the basin, capable of 100 Imp.gal. actual capacity for standard size. The water distribution system is of low-pressure enclosed downspray type and the drift eliminators are of two-pass type, offering minimum resistance to air flow with maximum removal of entrained moisture from the air leaving the tower. The unit is supplied with all items completely fabricated.

CPE 1678

Electrical air filters

An industrial type of filter for use on heavier dust burdens than those found in normal air filter applications has been developed by W. C. Holmes & Co. Ltd. Pre-collectors of the multi-cell cyclone type are normally fitted to arrest any large particles which may be present in the extract system.

The filter arrangement comprises an ionising section followed by one or more collecting plate sections in series. The combination of these sections is determined by the collection efficiency required and dust-holding capacity necessary to give reasonable periods between cleaning. The filters are normally arranged for dry removal of the dust, the complete filter section being vibrated to dislodge the collected dust which falls into storage hoppers below the filter. The cleaning operation occupies only a few seconds and is normally controlled on a timed cycle, which may be extended to incorporate automatic isolation of filter sections during cleaning when this is considered necessary. **CPE 1679**

'Terylene' at Moscow

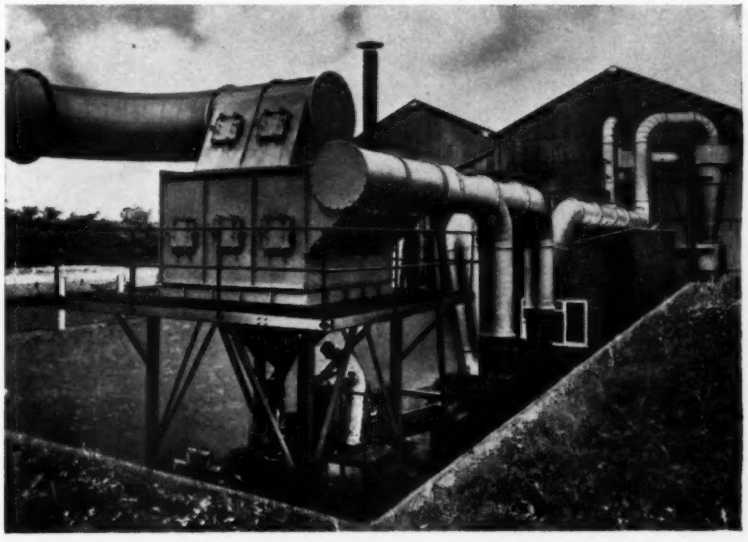
Many industrial *Terylene* products were shown by I.C.I. fibres division at the British Trade Fair, Moscow. The centre piece of the display was a section of 14-ply super-tensile *Terylene* conveyor belting which is claimed to be among the strongest ever made. Among other *Terylene* products were *Terylene*-reinforced hoses and tarpaulins made from the new *Terylene*/cotton core spun canvas, together with a range of mines ventilation ducting and *Terylene*/glass-fibre-laminated trays for dyestuffs processing.

CPE 1680

Diphenyl mercury

F. W. Berk & Co. Ltd. have developed a simple, direct process for the commercial production of diphenyl mercury. Formerly an expensive 'laboratory' chemical, it is now available in commercial quantities at a radically reduced price. The product is a white microcrystalline powder, containing about 56.5% of mercury, which melts at 125° to 126°C.

Apart from the applications of diphenyl mercury as a biocide and fungicidal treatment for timber and textiles, it can be used as an arylating agent and polymerisation catalyst. In the first case, a number of aryl metal compounds can be prepared and an



A Dallow Lambert MC200 wet deduster (under construction) serving a granulating system on which Fisons Fertilizers Ltd. carry out experimental work. Positioned downstream of the fan, it is thus above atmospheric pressure. The tank interior is rubber-lined due to the chemical properties of the dusts collected **CPE 1681**

extension of this method is possible in the field of metal organic polymers. In the second case, polymerisation of vinyl monomers such as styrene and vinyl acetate can be accelerated, and a recent patent indicates its utility in a polymerisation system for production of polypropylene. **CPE 1682**

Chemical road-tanker

An all-plastics container for the road transportation of hydrochloric acid or sodium hypochlorite is one of the latest achievements of Tough Plastics Ltd. The chemically resistant plastic called *Tufplas* prevents corrosion, formerly due to splashing of the metal casing. Manufacture of the tank entails forming *Vybak* sheets to the required shape and supporting them with a glass-fibre laminate bonded with polyester resin. The grey pigmented laminate is then given a coating of isocyanate resin.

The plastics road-tanker weighs about ½ ton as compared with a similar steel tanker which would scale 2½ to 3 tons. The container has been loaned to Bakelite Ltd. for the Interplas Exhibition at Olympia.

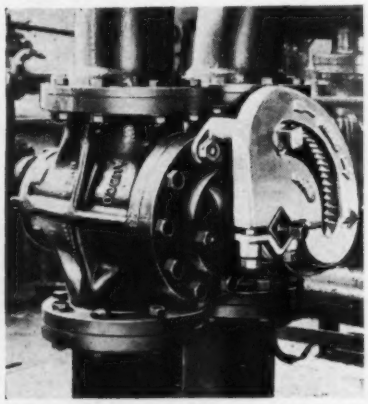
CPE 1683

Sinter crusher

The General Electric Co. Ltd. has recently developed a 60 in. by 24 in. *Pennsylvania* single-roll crusher for handling hot zinc-lead sinter. When operating, each crusher will be fed with hot sinter from a pallet 59 in. by 39 in. by 12 in. and, according to its setting, will give a product size of either 3 or 4 in. at a rate of 48 tons/hr.

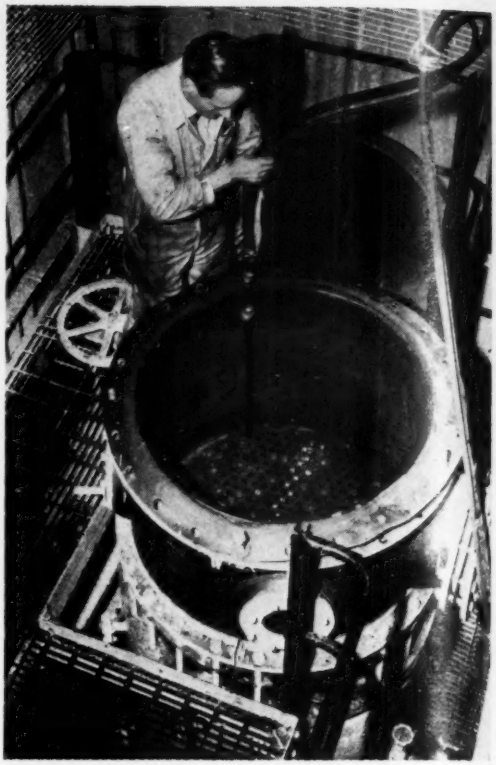
The crusher has a frame of fabricated construction housing an alloy steel-toothed roll and a readily adjustable steel breaker-plate. The crushing roll is driven at a speed of 20 rev./min. To avoid damage to the machine if it is overloaded, or if it receives an uncrushable object, spring-loaded toggles are fitted which allow the breaker plate to open and reset automatically.

CPE 1686



A light-duty gear unit designed by Audco Ltd. as an inexpensive mechanical means of operating certain larger wrench-operated Audco valves

CPE 1684



A recent new development of Vacu-Blast Ltd. is the descaling of graphite heat exchanger in situ by the introduction of the Vacu-Blast closed circuit system of grit-blasting. The blast nozzle from the Vacu-Blast Medium machine is shown being inserted into an extension lance which, in turn, is inserted into the ⅜-in.-diam. tube. The blast is controlled to a two-minute cycle per tube, and the grit is recovered by the vacuum integral with the machine from the collection cone

CPE 1685

PVC and PTFE pumps

Inerton pumps made by Glen Creston Ltd. have a high chemical resistance since they are made of either rigid PVC or PTFE. They contain no metal components in the path of the liquid. The standard range is machined from a special brand of rigid PVC which is tasteless, odourless, physiologically neutral and resistant to many of the most corrosive liquids.

The PVC *Inerton* pumps are successfully used for pumping acids, alkalis, aliphatic hydrocarbons, oils and many other liquids. They are not suitable for ketones, esters, aromatic and chlorinated hydrocarbons, acetone, ether and toluene. Maximum operating temperature of the PVC pumps must not exceed +60°C., but for special applications the PTFE pumps have a working temperature up to 200°C. **CPE 1687**

Digital system for process instruments

Rotax Ltd. have developed a system for the remote indication and recording of data from conventional process measuring instruments. The basis of the system is analogue to digital conversion at the instrument shaft without appreciable additional loading of the movement.

This simple converter is inexpensive and can be fitted to pressure gauges and other instruments, converting them to digital transmitters. Transmission of data readings can be automatic or on manual demand, either single or as part of a complete data logging system.

CPE 1688

Anti-static boot

A new type of boot, capable of dispelling static build-up, was demonstrated on the stand of Thos. W. Ward Ltd. at the recent R.O.S.P.A. Exhibition at Scarborough.

This footwear should be of particular interest to such industries as petroleum, chemical explosives, etc., where extra safety against highly inflammable materials is required. It is oil-resistant and has longer wearing soles than normal footwear. **CPE 1689**

Seen taking on a load of anhydrous ammonia at I.C.I.'s Chester Hill works in Sydney, this new Anglo-American tanker outfit is the latest addition to the fleet of Australian Fertilizers Ltd. The tractor is a 150-h.p. Leyland 'Super Beaver' equipped with a step-up auxiliary gear-box and two 55-gal. fuel tanks. It is coupled to a tanker manufactured by the J. B. Beaird Co. Inc., of Louisiana, U.S., which has a capacity of 6,330 gal.

CPE 1690

Drying unit

A.E.W. Ltd. are marketing a closed-circuit low-temperature drying unit for fast low-temperature drying at temperatures as low as 35° to 40°C. irrespective of atmosphere, humidity and conditions. Tests carried out show that the drying time for plastic granules, etc., is reduced to approximately one-sixth of the time taken with a standard oven and can be achieved at a much lower temperature resulting in improved quality mouldings and increased production capacity. It is supplied in two standard stock sizes: working chamber size 16 in. high by 18 in. wide by 18 in. deep, and 21 in. high by 24 in. wide by 24 in. deep. Other sizes are also available. **CPE 1693**

Rot prevention

I.C.I. Ltd. have produced a brand of ortho phenylphenol called *Topane* which, together with its water-soluble grade, *Topane* WS, provide the basis of an effective, simple and safe method of combating wet and dry rot in timbers and masonry. Unsightly stains in soft and hard woods are also prevented.

Topane can also be applied to textile finishes, rubberised fabrics and polyvinyl chloride to prevent mould growth. **CPE 1694**

Flowmeter

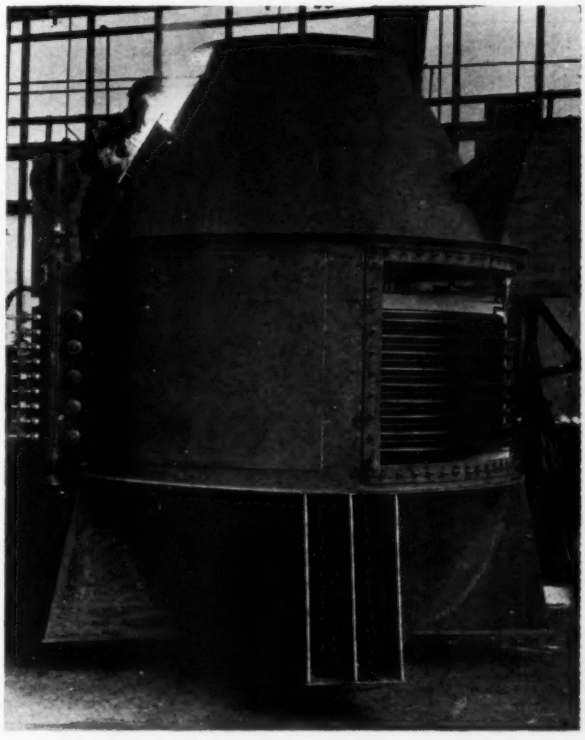
Rotron Controls Ltd., a member of the Elliott-Automation Group, showed a working model of their *Rotron* vortex-velocity flowmeter at the Mesucora Exhibition in Paris. The instrument is designed for positive and mass-flow measurements in the oil, gas, water and petrochemical industries. Its accuracy was checked against an independent and highly accurate predetermined electronic counter operating on a time base.

CPE 1691

Electric heating mantles

Isopad Ltd. exhibited their full range of electric heating mantles for laboratory flasks and glass plant at the Laboratory and Apparatus and Materials Exhibition last month. Their range included their *Multisize* design allowing the use of one heating mantle for several flask sizes from the smallest micro-mantle to 20-l. capacity; a design for 'flameproof areas', now also made for laboratory sizes and, in particular, for extraction units; *Isomantles* to heat glass plant up to 200-l. capacity and a 100-l. Q.V.F. glass still with controls; heaters for glass columns of all sizes; and *Isotape* flexible heating tape.

Their latest development was a high-temperature oven operating up to 500°C. (932°F.). A special arrangement of the heating elements ensures a uniformity of the temperature in all parts of the oven and the built-on mercury-in-steel contact thermometer, calibrated 0° to 650°C., gives automatic control. **CPE 1692**



A marine-type 'La Mont' exhaust gas, waste-heat-recovery boiler being manufactured at the Wolverhampton works of John Thompson Ltd. A modified unit of a standard range, the boiler has an evaporation of 4,000 lb./hr. at a working pressure of 100 p.s.i.g., fired by 166,000 lb./hr. of waste gas

CPE 1695

Nuclear Notes

250-kW TRIGA

A new addition to the range of TRIGA reactors, offered by Vickers-Armstrongs (South Marston) Ltd., is the increased power version of the standard Marks I and II models. The reactor is capable of steady-state operation at 250 kW and provides a maximum core flux of 10^{13} n/sq.cm.-sec. This increased flux greatly extends the usefulness of TRIGA. The initial excess reactivity will be 2.25% k/k and the core will contain the uranium-zirconium hydride fuel elements which provide the prompt negative temperature coefficient characteristic of TRIGA.

Study group for Pakistan

The Pakistani Atomic Energy Commission has retained the services of Internuclear Co. and Gibbs & Hill Inc. to make engineering and feasibility studies of possible applications of nuclear power in Pakistan. These two engineering groups will study the power needs and potentials of Pakistan, and from such studies make recommendations for nuclear power generation facilities best suited to the Pakistani power system. They will compare the costs of nuclear power with those of thermal and hydro power sources.

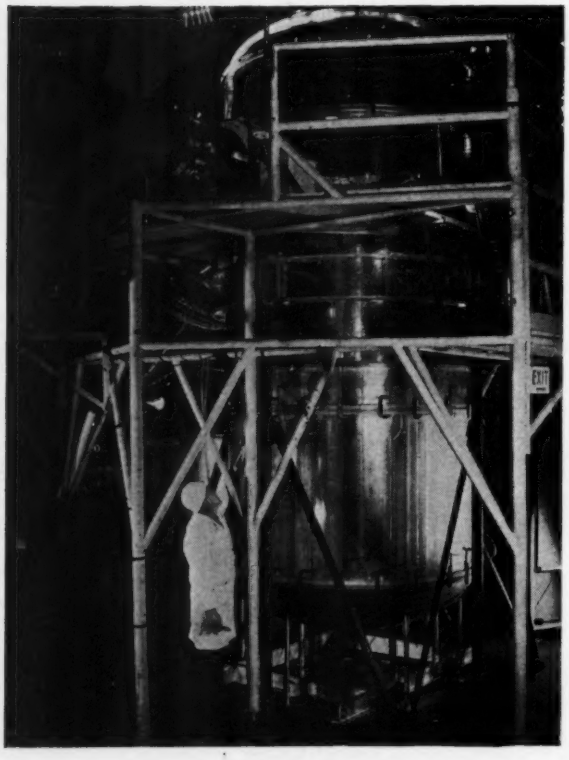
Atom forum

A number of Netherlands industries together with the Reactor Centre of the Netherlands (R.C.N.) have taken the initiative for the establishment of the Netherlands Atom Forum. Its object is to give publicity to the developments in the field of nuclear energy, especially in the Netherlands, and to attend to the documentation and information on the development and application of nuclear energy. The forum will in future represent the Netherlands in Foratom.

Nuclear-powered flight

The General Electric Aircraft Nuclear Propulsion Department (A.N.P.D.) is developing a direct-air-cycle nuclear propulsion system for aircraft under contract with the U.S. Air Force and A.E.C., following the successful operation of HTRE 3. Because of their nuclear power system the aircraft will be able to fly at extremely low levels over long distances and thus avoid altitudes where modern defence systems are most effective.

The results of HTRE 3 show the possibility of using the same materials to design a system which would power a modern gas turbine power plant.



Engineers at General Atomic Division of General Dynamics Corp. in San Diego using this transparent half-size scale model of the high-temperature gas-cooled reactor to simulate the gas flow conditions of the full-sized prototype reactor plant to be built at Peach Bottom, Pennsylvania. This 5-ton model is built of four concentric plexiglass shells and duplicates in every detail but in miniature

Gas entrainment

Scientists and engineers working on the experimental fast-breeder reactor at Dounreay have established the causes of the gas entrainment in the liquid metal coolant.

The core of the reactor can accommodate special fuel sub-assemblies similar to those which will be used in the prototype commercial power fast reactor, and these are being developed by the fuel element group. Experimental rigs for the prototype fast reactor fuels are also being irradiated in D.M.T.R. to provide the necessary data. Chemical processing of the first D.F.R. charge has been successfully carried out.

Fire-extinguishing medium

Metallurgists of the U.K.A.E.A. at Dounreay have produced a fire-extinguishing medium which is a eutectic mixture of dry powdered inorganic chlorides and fluorides inert towards the metal involved. The mixture is so chosen that its melting point is below the melting point of the burning metal.

The powders have been used, not only experimentally, but also to deal with actual fires at various experimental establishments both in and outside the Atomic Energy Authority.

Participation in reactor

The Atomic Energy Commission is inviting organisations using process steam to participate in a demonstration low-temperature process steam project incorporating a nuclear reactor. The Commission would construct and own the reactor. The participating organisation would be expected, as a minimum, to provide the site and steam utilisation facilities, operate the entire plant for at least five years as part of its process steam installation and pur-

chase steam produced by the reactor.

It is expected that the demonstration reactor would provide technical and economic data on the practicality of process heat plants in high cost fuel areas of the U.S., and also would provide operating experience in reactor technology in general.

U.S. grant

The United States recently informed the government of Indonesia that it will contribute $350,000 towards the cost of a nuclear research reactor project to be located at the Institute of Technology in Bandung.

Indonesia will be the 23rd foreign country to receive a $350,000 grant from the U.S. towards the cost of a nuclear research reactor project.

The Bandung reactor is a 100-kW Triga Mark II training, research and isotope-producing reactor to be constructed by General Atomics, a division of General Dynamics Corp. Fuel elements combine a zirconium-hydride moderator with 20% enriched uranium and are constructed specially for the reactor.

Fuel fabrication

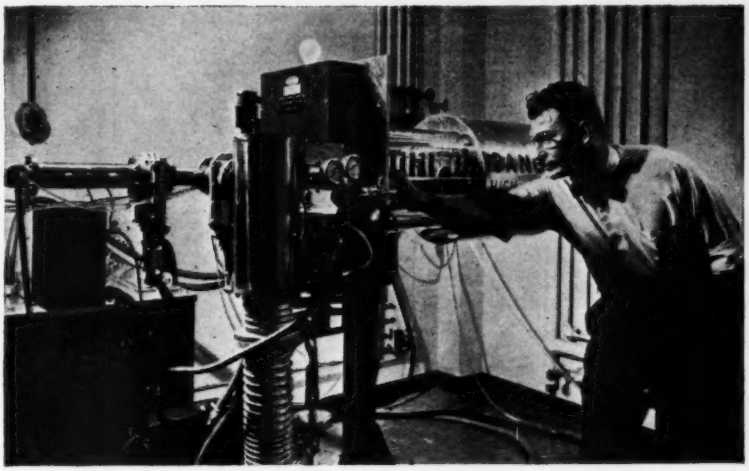
New techniques in fuel fabrication have been developed at the General Electric Aircraft nuclear propulsion department for use in prototypes of the nuclear propulsion system for aircraft.

A paper recently published by Walter J. Koshuba and W. J. Hendry disclosed that unusual techniques were used to fabricate a UO_2 dispersion wire-type fuel element for use in a hot critical experiment. Fabrication of these fuel elements required elevation of techniques which had previously been developed and which utilised hot extrusion as a method of primary reduction.

MOATA in Australia

Australia's second atomic reactor, MOATA, went critical recently. The new experimental assembly is necessary to carry out the Australian materials study of the high-temperature gas-cooled power reactor system and to enable measurements to be made of the behaviour of materials which could not be done readily with the high flux reactor HIFAR.

MOATA will have a maximum thermal power of 10 kW compared to that of 10,000 kW for HIFAR. The low power and inherent safety of MOATA would make it possible to give prior operational experience to people who will work on the bigger reactor.



The operation of a deuteron accelerator. This electronic device can analyse chemicals in 10 min. which by conventional methods would take an hour or more. It has been installed for experimental purposes in the laboratories of Shell Development Co., U.S.A.

Radioactive level gauge

A prototype device for remotely measuring the level of radioactive liquid wastes in underground storage tanks may prove to be the answer to a complex instrumentation problem. The instrument, developed and under test by General Electric's Hanford laboratories, is designed to hold up under the intense radiation, boiling temperatures and chemically active solutions in waste storage tanks.

Hanford's deeply buried tank 'farms', inside the U.S. Atomic Energy Commission's 600-square-mile reservation in Washington state, contain the high-level liquid wastes isolated from plutonium and uranium at chemical separations plants.

Accurate measurement of the level in each tank is important so that solutions can be kept in right concentration to prevent formation of sludge and as a warning in the event of a possible leak in one of the tanks.

The new device operates somewhat on the principle of a radio transmitter. An electrode antenna, sheathed in fused quartz, extends into the tank and feeds high-frequency radio current to the solution.

£ s d

CHEMICAL PLANT COSTS

Cost indices for the month of May 1961 are as follows:

Plant Construction Index: 184.8

Equipment Cost Index: 173.7

(June 1949 = 100)

£ s d

Yugoslavia asks for reactor

A request by the government of Yugoslavia for assistance in obtaining a TRIGA Mark II research and training reactor and for the supply of the necessary fuel (2.62 kg. uranium-235 in the form of 20% enriched uranium) was discussed by the board of governors of the International Atomic Energy Agency during their meetings in April. The reactor would be installed at the Nuclear Institute 'Jozef Stefan' at Ljubljana.

A project for the supply of the same type of reactor and nuclear fuel from the U.S. to Finland through the intermediary of the I.A.E.A. was approved by the Board of Governors early last year. The Yugoslav request suggests a similar procedure to be carried out within the framework of the co-operation agreement concluded between the Agency and the Government of the United States.

Carbon dioxide polymers

The probability of carbon dioxide-formed polymers has recently emerged from work at the Reactor Technology Branch of the U.K.A.E.A. The discovery was made on a mass spectrometer which has been built for investigating free radicals in gases at high pressure at A.E.R.E. Harwell. It was being used to examine commercial carbon dioxide from a cylinder at room temperature, when ions corresponding with groups $(CO_2)_{n+}$ showed. It was thought that the ions were formed from polymeric molecules already existing in the carbon dioxide, of the form $(CO_2)_2$, $(CO_2)_3$, etc., continuing as far as $(CO_2)_{23}$.

New Books

Ternary Systems. By G. Masing. Dover Publications, New York, 1960. Pp. 173. $1.45.

This is a translation of a standard German work on a topic on which an introductory text is much needed. Although the text and illustrations relate almost entirely to metallic systems, the principles are of general application and the spatial representation of the variation of three binary systems with temperature, allowing the representation on a triangular plot is of particular importance and application.

The introductory chapter of this book is a clear and concise description of the fundamentals of the subject. Unfortunately, this cannot be said of succeeding chapters, largely because of the confusion in the figures. Thus Fig. 8 on page 14 is repeated on page 21, and Fig. 9 on page 16 repeated on page 19 and again on page 25, neither lining up well with the descriptive matter. This occurs so frequently throughout the book as to be rather annoying.

For the metallurgist, to whom the book will most appeal, the most interesting chapters are those at the end of the book, chapters IX and X on particular alloy systems, but for the chemical engineer the lack of clarity in construction will leave much to be desired, particularly when compared with that of K. L. Butcher in *Trans. Inst. Chem. Eng.*, 1961, **39** (1).

One of the most satisfying features of this book is its price, which is remarkably low for a book of this type.

F. MOLYNEUX

Applied Thermodynamics. By S. H. Branson. Van Nostrand, 1961. Cloth, 30s. net; paperback, 22s. 6d. net.

This book introduces thermodynamics to the students of the applied sciences (and of chemical engineering in particular) and takes the subject sufficiently far for the student to perform useful engineering calculations. The subject matter is as follows: thermodynamic terms, basic thermodynamic properties, second law, diagrams and tables of properties, properties of real substances, some applications to gas handling, free energy functions, equilibria, and distillation.

In the earlier chapters, the difficult problem of dealing with the profounder aspects of the subject within a small space has had to be solved by quoting some of the results of the applications of such concepts as ' randomness ', ' probability ' and ' quantum mechanics ', without examining these in much detail. This may well be the way to stimulate further reading, but the student will have to make full use of the bibliography on the present work if he is to arrive at the other fountain heads.

Rather more space could have been devoted to the application of the tables of data of free energies and heats of formation readily available to chemical engineers, to more complicated problems involving alternative reaction paths and products, and to cyclic processes in the reaction field. It might also have been better to omit the stage-wise calculations and to dwell more on the problems of obtaining reliable data and correlations for phase equilibria in connection with distillation.

Nevertheless, the author has adopted an approach that should prove an acceptable introduction for many undergraduates who will profit from attempting the stimulating problems suggested at the ends of the chapters. The presentation is good, the text is accurately printed and the price of the work is very reasonable.

K. L. BUTCHER

Eléments de Physique Nucléaire. By D. Blanc et G. Ambrorino. Maison et Cie. 1960.

This is a clearly written and generally up-to-date account of the properties of nuclei, and nuclear interactions. Experimental methods and instruments are not discussed. Given an elementary knowledge of French, the text could be read by any capable student in the latter part of a degree course in physics or chemistry.

Short but interesting historical notes are given in the first chapter and various paragraphs throughout the book, leaving the main text generally free from the limitations of the historical approach. Unfortunately, this does not apply to Chapter 2, which is the least satisfactory in the book. Here an outline of quantum ideas is given in the too-familiar form of a mixture of old and new quantum theories.

Chapters follow on the systematics of stable and unstable nuclides.

The chapter on nuclear structure suffers from the inadequate theoretical background provided earlier in the book. The few paragraphs on particle physics seem rather inadequate. In particular the relationship between Fermi-Dirac particles and their anti-particles demands more discussion.

Thermonuclear fission is treated in great detail in a chapter which covers the basic principles of the subject.

There are some useful appendices, and indices of authors and subjects.

J. W. WARREN

Handbook of Chemistry and Physics. Editor-in-Chief, Charles D. Hodgman. Chemical Rubber Publishing Co., 1960. Pp. 3,481. $12 net ($12.50 net outside U.S.A.).

Tables for Identification of Organic Compounds. Editor-in-Chief, Charles D. Hodgman. Chemical Rubber Publishing Co., 1960. Pp. 241. $7 net ($7.50 outside U.S.A.).

The 42nd edition of this classic contains considerable revised data. In certain instances entire tables have been revised; in other cases only a portion of the table has required alteration. Among the revised data and information are:

- Atomic weights (up to Mendelevium Z = 101, but not, strangely, Nobelium Z = 102).
- Electronic configuration of the elements
- Trade names of plastics
- Analytical reagents
- Volumetric primary standards
- Efficiency drying agents
- Properties of refractory materials
- Nuclear spins
- Definitions

In addition, new tables have been added to this edition of the handbook.

A special supplement which includes tables for identification of organic compounds, appears for the first time. The supplement is a compilation consisting of more than 4,380 parent compounds and brings together for the first time such a large quantity of data directly applicable to qualitative organic analysis. Included in these tables are the main representatives of the more common classes of organic compounds. This is a welcome addition and should prove of utmost importance to physical chemists and chemical engineers. Since it is intended to revise these tables quite frequently, readers will not have to wait too long until newer materials are included (they are encouraged by the editor to submit any data on new materials).

I.L.H.

CPE DIARY

JUNE 26 TO JULY 7 AND JULY 10 TO 21 O.E.E.C. seminars on **nuclear science** for university and technical college staff to be held respectively at Saclay and Harwell.

JULY 6 TO 8 AND JULY 10 TO 12 The 16th Annual **Electronics, Instruments and Components** Exhibition and Convention of the Institution of Electronics to be held at the College of Science and Technology, Manchester.

AUGUST 6 TO 12 Eighteenth International **Conference of Pure and Applied Chemistry** to be held in Montreal, Canada. Details from the Secretariat of the Congress, National Research Council, Ottawa, Canada.

AUGUST 15 TO 17 **Cryogenic Engineering** conference sponsored by the University of Michigan in Ann, Arbor, Michigan. Details from Chemical Engineering Department, University of Colorado, Boulder, Colorado, U.S.

AUGUST 28 TO SEPTEMBER 1 International **Heat Transfer Conference** to be held at the University of Colorado, U.S. Further details from Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

SEPTEMBER 27 TO OCTOBER 4 International Conference on **Heating, Ventilation and Air Conditioning** to be held at Olympia. Details from Industrial Exhibitions Ltd., 9 Argyll Street, London, W.1.

It is now five years since the retail book department of Leonard Hill Ltd. was opened. Many readers have written to us during this period, and many have shown their pleasure in the fast service we always endeavour to give, by sending many further orders.

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Personal Paragraphs

★ Four new assistant managing directors of Castrol Ltd. have been appointed as from January 1, 1962. They are **Mr. J. A. V. Watson,** O.B.E., who will be responsible for research and development; **Mr. L. G. Packam,** for the overseas department; **Mr. C. E. R. Millidge,** for the engineering division; and **Mr. A. A. Barr,** for publicity.

★ **Mr. R. B. Snapp,** who has been associated with American Machine & Foundry Co. since 1957, has been appointed divisional vice-president of A.M.F. in charge of its Washington office.

★ **Mr. J. F. Widman,** director and general manager, Chemicals Division, of Union Carbide Ltd., is to retire from the board of the company. He will be taking up a new assignment with Union Carbide International Co.

★ **Mr. T. L. Birrell** is to retire from the board of the British Xylonite Co. Ltd. after 33 years' service. He was elected in 1947 and, since 1949, has been managing director of the Malex Division. He is joining the board of Yarsley Research Laboratories Ltd. at Chessington.

★ **Mr. M. Willcocks,** O.B.E., who was until recently on a special assignment with Shell Refining Co.'s head office in London, has been appointed manager of Shell's refinery at Geelong, Australia. He joined Shell in 1936 and has served at the central laboratories and Shell Haven and Heysham refineries.

★ It is announced by Albright & Wilson that **Mr. F. G. Pentecost** has resigned from the board of the company following his retirement from the board of A. Boake, Roberts & Co. (Holding) Ltd. **Mr. B. White,** who succeeded Mr. Pentecost as chairman of the latter company in April, has been appointed to the board of Albright & Wilson Ltd., and **Prof. D. M. Newitt,** F.R.S., until recently Courtauld Professor of Chemical Engineering, Imperial College of Science and Technology, has been appointed a part-time director of Albright & Wilson Ltd.

★ Ambuco Ltd. announce the appointment of **Mr. E. W. F. Clements** as a director of the company. Mr. Clements is chief mechanical and electrical engineer of the Consolidated Gold Fields of South Africa Ltd.

★ **Mr. R. H. Wilson** has been appointed to the board of directors of Ciba (A.R.L.) Ltd. Mr. Wilson, who joined the company (then known as Aero Research Ltd.) in 1954, was initially associated with the development of *Araldite* epoxy resins and was appointed general sales manager last year.

Mr. M. Willcocks

Mr. R. H. Wilson

Mr. R. B. Snapp

★ **Nr. N. Elce,** F.R.S.A., director and chief mechanical engineer of Associated Electrical Industries (Manchester) Ltd., has retired after 41 years with the A.E.I. group of companies. He has been appointed consultant to the managing director at Manchester. Mr. Elce is a member of the Manchester and District Advisory Council for Further Education. He has served as an honorary consultant to the Department of Atomic Energy and on the thermodynamics committee of D.S.I.R. In 1957 he was elected a vice-president of the Institution of Mechanical Engineers. He is a member of the steering committee of the National Engineering Laboratory.

★ **Mr. S. W. Martin** has relinquished his position as managing director of the Staveley Iron & Chemical Co. Ltd., but continues as chairman. He is succeeded as managing director by **Mr. N. C. Macdiarmid,** a director of Stewarts & Lloyds Ltd., who joined the Staveley board in September 1960.

Orders and Contracts

Crystalline urea

The chemical plant division of the Power-Gas Corp. Ltd. recently received an order from Werkspoor N.V. of Amsterdam for three installations for the crystallisation of high-purity urea. Each installation, which produces 100 tons/day of crystalline urea with low biuret content by the *Krystal* process, consists of two vacuum crystallisers arranged in parallel and complete with all ancillary equipment. These units form part of the supply for three individual urea plants to be built in Russia, and delivery is to be made during 1961.

Condensing plant

Following on the recent order for four complete sets of condensing and feed heating plant of new design for Tilbury 'B' power station, the Richardsons Westgarth Group have received a further order from the Central Electricity Generating Board for the condensing plant for use with a 300-MW turbo-generator at West Thurrock power station. The value of this order is approximately £300,000.

Silicon steel processing

The General Electric Co. Ltd. has supplied to Richard Thomas & Baldwins Ltd. a number of electric furnaces for the processing of *Alphasil*, a silicon steel of the grain-orientated type used in the construction of cores for transformers and reactors. The furnaces are installed in the Cookley works of the company at Brierley Hill, near Birmingham, and comprise a continuous strip decarburising furnace, a continuous strip inter-annealing furnace and a number of bell-type furnaces for high-temperature annealing.

Including the cooling chambers the decarburising furnace is nearly 400 ft. long and is believed to be the longest of its type in Europe. It is of the roller-hearth type and receives steel strip up to 32 in. wide. Having a maximum electrical rating of 1,700 kW it operates with a controlled atmosphere. The inter-annealing furnace is of similar design to this furnace, but its maximum electrical rating is 2,000 kW.

Sewage purification works

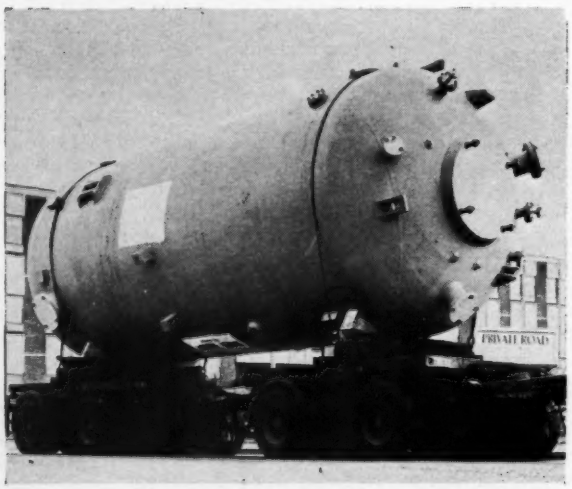
Brookhirst Igranic, a company in the Metal Industries Group, is to supply electrical controls for the Deephams sewage purification works of the East Middlesex main drainage scheme. The order is valued at £77,000.

Polystyrene plant

An agreement has been signed in Bucharest between Masinimport, the Rumanian State enterprise for foreign trade, and Petrocarbon Developments Ltd. for the supply of a polystyrene plant. The value of the U.K. supplies, including fees for know-how and engineering services, will exceed £800,000. This is the first major order for a chemical plastics plant since the signing of the trade agreement between Rumania and the U.K. last autumn.

The plant will produce all types of general-purpose and toughened grades of polystyrene, as well as high molecular weight, a variety of special grades and expandable polystyrene. Also included in the supply is a plant for the continuous production of expanded polystyrene board.

The plant will be highly automated both with regard to the process side and with regard to material handling. An essential feature of the plant is its extreme flexibility, which enables production to be changed rapidly from one grade to another and also permits the running of a number of grades simultaneously.



The shell of the first Lurgi gasifier to be made in the U.K. supplied by the Power-Gas Corp. Ltd. to the order of Humphreys & Glasgow Ltd. The shell, together with coolers, waste-heat boilers and other equipment, for the Lurgi gas-making plant at Westfield, Fife, was manufactured in the Stockton works of Ashmore, Benson, Pease & Co. Ltd.

Acid recovery

Process Plant Contractors (Campbell) Ltd. have been awarded a contract valued at about £500,000 for the design, supply and construction of an acid recovery and storage plant for British Sidac Ltd., cellulose manufacturers, at their works at St. Helens. This plant is an extension to their existing facilities and is scheduled for completion in 15 months. The contract will be executed in collaboration with William Neill & Son (St. Helens) Ltd., who will supply the buildings, tanks and vessels.

Continuous reforming plant

Simon - Carves Ltd. have been awarded a contract by the Eastern Gas Board for the supply and erection of an Otto continuous reforming plant at Dunstable works to produce 5 million cu.ft./day of enriched town gas from liquefied petroleum gases. The order includes for the supply of shift conversion plant for the detoxification of the gas and for feedstock storage and handling facilities.

Polymer plant

Blaw Knox Chemical Engineering Co. Ltd. have been awarded a contract by Bexford Ltd.—who are associated with BX Plastics and Ilford Ltd.—for the design, engineering and construction of a plant for the production of polymer. This plant, which is to be constructed on the Bexford site at Manningtree, Essex, is scheduled for completion later this year.

Maleic anhydride plant

Bombrini Parodi-Delfino S.p.A. has awarded an engineering contract to Scientific Design Co. Inc. for a maleic anhydride plant to be built at Colleferro, Italy. The 10-million-lb./yr. facility will use Scientific Design's process based on air oxidation of benzene. The estimated date of completion will be by the middle of 1962.

The new contract brings the total of maleic anhydride projects in progress or completed since 1954 by Scientific Design to 17.

CPE Company News

Fertiliser factory

Simon-Carves Ltd., a member company of Simon Engineering Ltd., is to supply a sulphuric acid plant and a single superphosphate plant as part of a new fertiliser factory which is to be built at Sukulu for the Uganda Development Corp. Ltd.

The output will be 25,000 tons p.a. of granulated single superphosphate made from locally mined apatite rock. The acid plant will produce 30 tons/day of 98.5% sulphuric acid from imported sulphur and the superphosphate plant will comprise a den for continuous production of single superphosphate, a granulation plant, a bagging plant, and the ancillary conveyors, fume scrubbers, etc.

Monochloracetic acid plant

Courtaulds Ltd. announce plans to erect a plant to manufacture monochloracetic acid and sodium monochloracetate. These chemicals, which are not at present made in this country, are used extensively in hormone weedkillers and for detergents, pharmaceuticals, dyestuffs and photographic and other materials.

The plant will be located at the Spondon factory of British Celanese Ltd. and will utilise a continuous process capable of giving high yields. Supplies will be available early in 1962.

Acid plant

Whiffen & Sons Ltd., a member of the Fisons Group of companies, announce plans to manufacture both cyanuric and trichlorcyanuric acids. The plant will produce 350 tons p.a. of each acid. This output will enable the company to meet total U.K. requirements and provide a surplus for export, and provision has been made for expansion of output as necessary. It is estimated that the initial plant will cost £100,000.

Ethylene dichloride plant

British Hydrocarbon Chemicals Ltd.'s large tonnage plant at Grangemouth for the manufacture of ethylene dichloride will come on stream in July/August 1961. The bulk of the production of ethylene dichloride will be shipped to the Distillers' Plastics Group factory at Barry, South Wales, where it will be used for the manufacture of vinyl chloride and hence PVC.

Effluent problem

An arrangement has been made between Head Wrightson Processes Ltd. and the *Alfloc* water-treatment service of I.C.I. Ltd. whereby the two concerns will collaborate in the assessment and solution of problems relating to treatment of trade and other wastes before discharge to sewers or water courses. In addition, a special study will be made of the re-use of water within industry with the view to alleviating problems of water supply and of disposal of wastes.

Whenever possible, the approach to the solution of problems will follow chemical engineering practice to facilitate the incorporation of standard plant of proved performance and to avoid expensive civil engineering works.

Nuclear engineering company

I.C.I. Ltd. (metals division), Rolls-Royce Ltd. and the Rio Tinto Co. Ltd. have jointly formed a new company, Nuclear Developments Ltd., to operate in the field of civil nuclear engineering in collaboration with the atomic power consortia.

Each of the participants has experience which will be appropriate to the future role of the new company in nuclear engineering. This will enable Nuclear Developments Ltd. to meet demands as and when they can be met by private industry, for fuel preparation and fuel element manufacture for civil reactors.

Chemical engineers move

Kestner Evaporator & Engineering Co. Ltd. are to transfer their London works from New Cross to Greenhithe.

The site at Greenhithe covers 10 acres and is adjacent to the new Dartford tunnel, so that direct access from and to the north can be made by by-passing London.

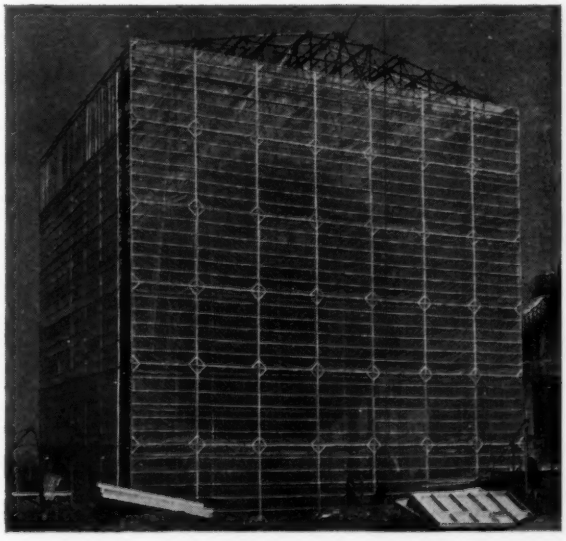
The new works will gradually be brought into operation commencing this month and completing towards the end of the year. Among other items there will be an extensive new laboratory embodying facilities for pilot plant and experimental testing.

The old Kestner works in the New Cross area will be acquired by the London County Council for demolition.

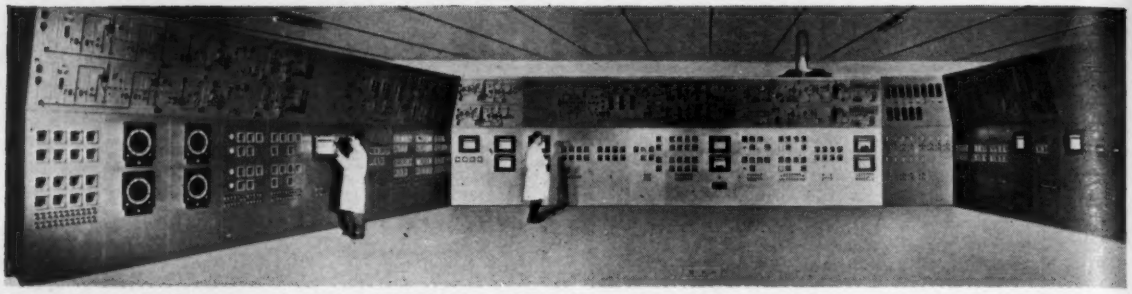
Industrial power plant

The General Electric Co. Ltd. and Richardsons, Westgarth & Co. Ltd. announce that they have decided to pool their resources for the design, development, sales and manufacture of heavy electricity generating and industrial power plant.

The manufacture of all plant covered will be shared and initially based on current G.E.C. designs. R.W. will concentrate on the design of industrial power plant with the object of supplementing existing G.E.C. designs and widening the range of plant offered. They will continue to be responsible for the sales and manufacture of condensing and feed heating plant, rotary water strainers, evaporators and shell boilers of their own design and for land water-tube boilers of Foster Wheeler design.



To give weather protection to men erecting this butadiene storage sphere for I.C.I. Heavy Organic Chemicals Division at Wilton Works, Yorkshire, Wessoe Ltd. have constructed this shelter. Each panel consists of heavyweight 'Visqueen' polyethylene building sheet made by British Visqueen Ltd. The structure also serves to isolate sparks caused by electric welding and to allow day work to continue without the need for artificial illumination



Destined for a £2-million Russian chemical works being built by Vickers-Armstrongs, this 100-ft. instrumentation panel is part of £200,000-worth of automation equipment made at the Lanarkshire works of Honeywell Controls Ltd. There will be nearly 200 closed loops for controlling temperature, pressure, flow, liquid level and other quantities

CPE World News

SPAIN

Oil company

A new Spanish oil company is to be formed to build the refinery in which the Spanish Government will have a holding of 52%, Compania Iberica de Petroleos a holding of 4%, the Ohio Oil Co. 28% and the other Spanish interests 16%. The $18-million capital of the new company will be entirely provided by the Ohio Oil Co. Machinery will account for 84% and the remainder will be in dollars.

The capacity of the new refinery will be about 1,200,000 tons p.a. The Ohio Oil Co. will supply up to 10 million tons of crude oil in the first 10 years from its oil wells in Libya provided no oil is discovered in the Spanish Sahara.

GERMANY

Company taken over

As a result of a cash and share bid worth £1,500,000, Laporte Industries has acquired the German chemical company, Elektro-chemische Werke München A.G. This transaction establishes in the chemical field a pattern already familiar for such industries as paper and textiles, prompted for the main part by Common Market developments. Laporte now has a foothold in this market.

E.W.M. was founded in 1911 and is one of the major producers in the German Federal Republic of hydrogen peroxide by the electrolytic process, organic and inorganic peroxides, persulphates and chlorites and other chemical products. The main products of E.W.M. are also produced in the U.K. by Laporte Chemicals Ltd. which is at present operating E.W.M.'s process for the manufacture of sodium chlorite at Luton.

AUSTRALIA

Continuous tar distillation plant

Chemical Engineering Wiltons Ltd. have designed and engineered the first continuous tar distillation plant in Australia and a naphthalene recovery plant which are shortly to be erected by Simon-Carves (Australia) Pty. Ltd. to the order of the Australian Iron & Steel Pty. Ltd. The tar plant will distill 215 tons/day of crude tar and the naphthalene plant will produce 15 tons/day of purified naphthalene.

TANGANYIKA

£3 million refinery

The Tanganyika government is considering proposals for building a £3-million oil refinery in Dar-es-Salaam which it is proposed would be capable of supplying Tanganyika's entire requirements of petroleum products. If the proposal is accepted by the government, negotiations will take place as soon as possible.

UNITED STATES

Ammonia plant

Nitrogen Products Division have announced plans to build a new ammonia plant in Big Spring, Texas, which will be operated by Cosden Petroleum Corp. The new plant will supply fertiliser to the rapidly expanding agricultural area of West Texas. It is expected to be in operation early next year and will produce more than 60,000 tons of ammonia p.a. The plant will adjoin the Big Spring, Texas, oil refinery of Cosden.

Patent infringement

Ionics Inc. has filed two complaints of infringement of U.S. patents covering its electric membrane processes for water desalination. American Machine & Foundry Co. was named in one complaint referring to four patents issued to Ionics to cover electric membranes, their commercial manufacture and use in electrodialysis systems and other features involved in the operation of electrodialysis systems.

Aqua-Chem Inc., formerly Cleaver-Brooks Special Products Inc., was named in a second complaint covering five patents.

FRANCE

Expansion in organic chemicals

The Companie Francaise des Matieres Colorantes, a subsidiary of the Kuhlmann Cie., is expanding its production of organic industrial chemicals and intermediates. At present, a formaldehyde plant is under construction. The production of maleic anhydride is being increased from 250 to 375 tons/month. Besides this, it is planned to build a new plant for making phthalic anhydride according to the Scientific Design Co.'s process (see CPE, 1961, **42**, 198).

SWEDEN

Polyethylene plant

Union Carbide Corp. and Stockholm's Superfosfat Fabriks Aktiebolag, usually called Fosfatbolaget, are to participate in a joint venture to construct a 35,000,000 lb. p.a. polyethylene plant in Sweden. It will be completed in 1962 and will represent the first polyethylene manufacturing plant in the country. It will have sufficient capacity to satisfy not only the Swedish market but also to export to the Scandinavian area generally.